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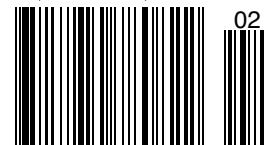
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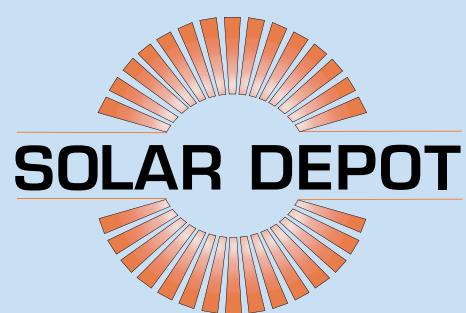
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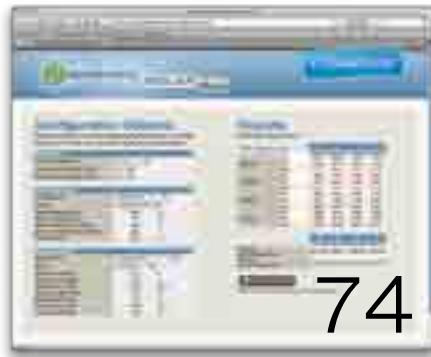
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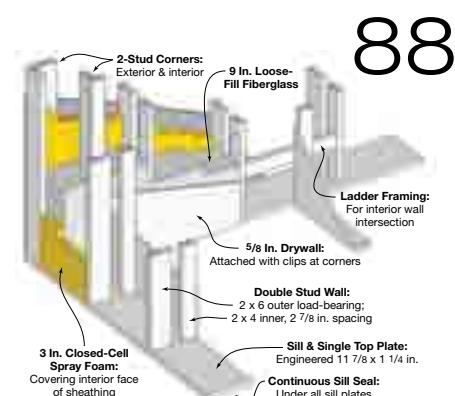
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## Solar Parity

**S**olar energy not only has staying power—but growing power, too. PV has been around for several decades (and solar water heating for even longer) and, in the past few years, the industry has continued its growth despite a weak economy. Megawatts of PV capacity are projected to be installed in the United States this year. The good news for consumers is that, as PV system costs continue to drop, solar electricity is getting more competitive with conventional sources.

Last summer, “Solar and Nuclear Costs—The Historic Crossover,” a report co-authored by Duke University professor John Blackburn, showed that PV energy generation in his neck of the woods—North Carolina—is now “less expensive per watt than new nuclear generation.” The findings, which factor in incentives, are an “apples to apples” comparison, according to Blackburn.

He says that declining manufacturing expenses and advances in installation techniques are two factors contributing to dropping costs of both PV and solar hot water systems. The report considered “incentives, interviews with PV installers and solar trends studies” to derive estimates for PV generation costs, which it compared to cost estimates to build power plants—specifically, new nuclear plants.

Three technologies—coal, natural gas and nuclear energy—make up about 90% of annual electricity generation in the United States, with renewables only contributing a small fraction to the total mix. But that’s changing with increased interest in renewable energy at all levels. You’ll read this good news—and how-tos—first at *Home Power*, where we’ve been keeping readers informed on the latest efficiency and RE developments for more than two decades.

—Claire Anderson, for the *Home Power* crew

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—Thomas A. Edison

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**2**

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**3**

## Install the Inverter

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# The State of Incentives

Overwhelming demand for clean, renewable energy is prematurely depleting some incentive programs.

Megan Murillo and her husband Sergio purchased a 1950s ranch-style home two years ago and hoped to one day put in a PV system to offset the energy use of their growing family.

The couple took steps to make the home more energy efficient—upgrading the insulation, windows, and appliances. In the summer of 2010, they at long last contracted with a local installer and put down a deposit to have a 2.8-kilowatt PV system installed.

But when their local utility provider, Black Hills Energy, discontinued its \$2-per-watt solar energy rebate program last October without any warning, the couple had to put their plans on hold.

"We were completely shocked. Had we had any notice, we would have made sure to get our paperwork in earlier," says Megan.

The Murillos are not alone. Homeowners throughout the country are in limbo, waiting to see if the incentive programs in their service areas will be reinstated.

The stop/start cycle affects programs of all types and sizes. Two leading electricity providers in Arizona—Salt River Project (SRP) and Arizona Public Service (APS)—experienced such high demand that their programs have opened and closed quickly. Florida's GRU program, Vermont's SPEED program, and Oregon's Volumetric Incentive Rates and Payments program—all with feed-in tariff models—also closed soon after opening because of overwhelming response.

Last year, Florida's Solar Energy Systems Incentives Program closed with a \$52 million backlog in unpaid rebates to homeowners, and New Jersey's solar program shut down several times in years past because applications far outpaced available funds.

"Incentive design is tricky, and program officers don't always get the level right," says Amy Heinemann, a policy analyst with the Database of State Incentives for Renewables and Efficiency ([www.dsireusa.org](http://www.dsireusa.org)). "Incentive levels are [sometimes] either set too high, or there is a lot of pent-up demand for incentives and the program runs through funding quickly."

More and more incentive providers are adopting "transparent" tracking systems so customers know how much funding is left in a program budget and when—or at what capacity level—the program will step to the next lower rebate tier (or shut down). This allows installers and customers to plan accordingly.

Some programs, like the California Solar Initiative, Pennsylvania Sunshine, and Xcel Energy Solar Rewards

Program in Colorado, have planned step-downs that happen at a certain date or when a certain capacity benchmark is met. Others, like Energy Trust of Oregon's Solar-Electric Buy-Down, respond to market conditions and step down the incentives when there is high demand.

Unfortunately for the Murillo family, Black Hills managed its program behind closed doors, and did not make the Public Utilities Commission and stakeholders aware of growing inability to provide incentives. Ultimately, incentives that were set too high for too long depleted the budget.

The Rapid City, South Dakota-based utility, which serves nearly 100,000 customers in the Pueblo region of southeastern Colorado where the Murillos live, declined an interview with *Home Power* but issued an e-mail statement citing high demand and insufficient funding as the reason for the closure.

"When you have surprising decisions like Black Hills', it really spooks the industry and erodes public trust," says

**The DSIRE website publishes the current state of incentives nationwide.**



Neal Lurie, director of the Colorado Solar Energy Industries Association. "A decision like this does not just affect the solar businesses in that region. There is a ripple effect that impacts not only homeowners but all the businesses throughout the supply chain."

After the housing market declined, former builder Jarred Johnson found a fresh start in solar energy. He and his partner, Robert Harford, invested more than \$300,000 into starting a solar energy installation business in Pueblo, hoping to capitalize on the solar boom in the region. Their business, Yes Solar Solutions, had only been up and running for 18 months when Black Hills discontinued its program.

According to Lurie, Black Hills actions violate PUC Rule 3658, which states that investor-owned utilities are not authorized to reduce (or discontinue) the standard rebate—only the PUC has the authority to do so.

The utility submitted its report in November 2010, which revealed that the solar program has a \$12 million deficit.

According to Jeff Lyng, renewable energy policy manager in Colorado governor Bill Ritter's Energy Office, any number of steps—such as bringing in a third-party administrator to manage the program, reporting program data more regularly to allow the PUC to respond accordingly, and adding a third-party leasing option to the program that would have stretched program dollars further—could have prevented the situation.

The larger concern among stakeholders is what precedent the situation could set for utility compliance with solar programs at both the state and national levels.

"If utilities can show that the costs of renewable energy are too high, then they could and might make the case that they don't have to comply with renewable energy standards that states have imposed," Lyng says. "In this case, our argument is that the program has been effectively mismanaged, and there are things that can be done to bring it back into the black and things that should have been done to keep it operating in the black."

Stakeholders, including Colorado's Energy Office, offered several approaches to help Black Hills restore the program and ensure market stability. Among the most notable is to advance ratepayer funds from future program years—a mechanism made possible by Colorado House Bill 1001, which took effect last spring.

## Incentives on the Decline

Incentives—rebates, FITs, tax credits, and renewable energy credits—were intended as temporary measures to lower the costs of renewable energy systems and make them more competitive with conventional electricity sources.

With the help of incentives, market forces have been successful in driving down the costs of renewable energy. For example, the average installed cost of residential batteryless, grid-tied PV systems (before incentives) has dropped significantly—it was about \$6 per watt in 2010, compared to \$8 per watt in 2006 and \$10 per watt in 2001.

## Community Choice Aggregation

The controversial actions of large utility companies have pushed some communities to pursue renewable energy goals on their own terms. Some states, like Vermont and Oregon, are using independent third-party administrators to manage programs.

Other states—Massachusetts, Ohio, New Jersey, California, and Rhode Island—are allowing community choice aggregation (CCA), which allows cities and counties to combine the purchasing power of residents and businesses to choose their energy sources instead of automatically being stuck with their utilities.

The concept grew from frustrations that utility providers weren't meeting the energy goals of individual communities—whether it be using renewable resources or energy expense. By combining the purchasing power of many individuals, these programs give customers more leverage in the marketplace. "Buying in bulk" can keep rates on par or often lower than utility rates, and allows communities to meet more aggressive renewable energy goals.

The counties of Cape Cod and Martha's Vineyard in Massachusetts led the way with the country's first CCA legislation in 1997 and forming the Cape Compact Light. Ohio followed suit in 1999, establishing the nation's largest CCA, the Northeast Ohio Public Energy Council.

More recently, the County of Marin and seven other cities in California broke away from Pacific Gas & Electric to form the nonprofit Marin Energy Authority to administer a clean energy program. The authority offers its customers a 78% fossil-free power mix—roughly twice the renewable energy content of PG&E's offering. The authority is able to maintain competitive rates by keeping overhead down with a four-person staff and a team of consultants—no shareholder profits or extraneous operating costs.

While CCAs use various models of operating, advocating for energy rights is at the core of their missions. Roughly 1 million Americans currently receive service from CCAs. And that number may be growing.

In Boulder, Colorado, for example, voters overwhelmingly supported an occupation tax on Xcel Energy, and the city chose to explore its options for achieving a greater mix of renewable energy and hold off on renewing its franchise agreement with Xcel.

"The basic idea is that Black Hills shaves a little here or there from future years when less money will be needed to provide incentives for renewable energy," Lyng explains. "Not all monies are brought forward, but a portion from, say, 2016 and 2017 can be reallocated to 2011 to support the need for incentives and stimulate continued market growth today that will bring costs down even more tomorrow."

House Bill 1001 upped the state's renewable energy target from 20% to 30% by 2020, making Colorado's renewable portfolio standard (RPS, the amount of the utility or state's electricity that needs to come from renewables) the second

highest in the nation behind that of California's mandate of 33% by 2020.

Carrying out that goal is where it gets tricky, and where Black Hills may get a break. According to Black Hills' latest compliance plan, the utility has already met its 2011 threshold for retail usage through the solar program. (However, the report also indicates that the company will not comply with wholesale requirements for 2011.) If the utility can prove that the solar program is not necessary in the short term to meet the larger goal of generating 30% of its energy from renewable sources by 2020, then state regulators may have to capitulate.

Another factor is that the latest RPS measure did not raise the statutory cap that investor-owned utilities can collect from customers to meet those goals. Black Hills maintains that the surcharge to support the solar program—currently capped at 2% of a ratepayer's monthly bill—is not sufficient to fund additional program costs.

Yet, allegations of mismanagement stem from the fact that Black Hills made only two rate reductions in the time that Xcel Energy, Colorado's largest utility, gradually adjusted its REC incentive prices seven times to coincide with declining prices for PV modules and increased incentives at the federal level. Xcel implemented a program where rate drops are visible with daily updates on the company's website.

"Black Hills' incentives were way too high for the size of the company and service area. They were trying to keep pace with Xcel Energy, but Black Hills is a guppy and Xcel is a whale," says Greg Severance, director of Public Works at Pueblo County.

Last summer, Severance was among a small minority of local officials who testified at Pueblo city council meetings against renewing the franchise agreement. The renewal passed with a 6-to-1 majority, before possible rate hikes and compliance issues were brought to light.

"I would have been one of the most vocal voices in the crowd had I known what they were planning," Megan says. While she and her husband may explore different options for financing a PV system, she says it is unlikely that in the current economy they will be able to install the system without the rebate that they would have received from Black Hills. Prior to the announcement, Black Hills' solar program offered homeowners a rebate of \$2 per watt—plus a one-time renewable energy credit payment of \$0.50 per watt.

The moral of the story: Never put off until tomorrow what you can do today. Black Hills' solar rebate program may well return, but it will most likely be reintroduced with lower incentives.

—Kelly Davidson



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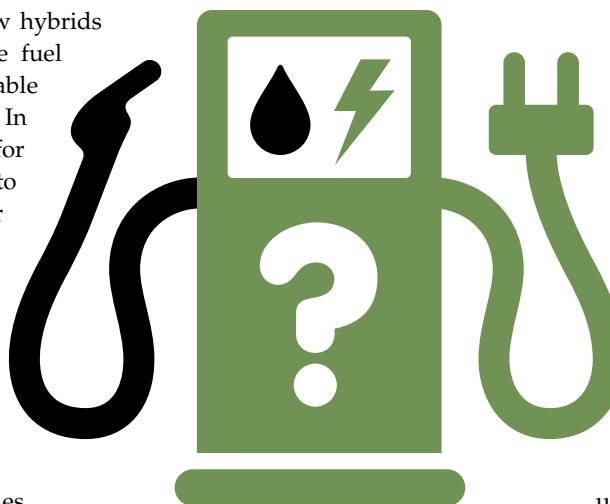
# Green Car Drive-Off: EV vs. Hybrid vs. Gas

Electric cars have arrived and new hybrids are proliferating. As a result, the fuel economy of the average affordable car is finally starting to climb. In fact, there are so many choices for efficient cars that it can be hard to know which technology is best for the environment and your wallet.

Weighing your green options gets more complicated because of regional differences in gasoline prices, electricity rates, and how the electricity (to power your EV) is produced.

"Greenhouse gas emissions associated with plug-in vehicles depend strongly on which power plant is generating the electrons that charge the vehicle," said Jeremy J. Michalek, associate professor of mechanical engineering and public policy at Carnegie Mellon University.

To start my region-by-region comparison, I assumed 15,000 miles of driving per year. To determine CO<sub>2</sub> emissions for gasoline, I used Argonne National Laboratory's well-to-wheels factor of 23.7 pounds of CO<sub>2</sub> for each gallon



burned in your car. The CO<sub>2</sub> numbers for electricity come from the Environmental Protection Agency's eGrid data. Rather than making a small adjustment for primary energy source extraction, transportation, and processing, I used the eGrid numbers at face value. That's because those numbers—the best ones anybody has these days—were produced in 2005, and the grid is getting greener every day. (I told you it was complicated.)

For electric car efficiency, I used the EPA's value of 3.6 miles per kWh, which accounts for losses during EV charging. I assumed 30 mpg for a fuel-efficient gas car, and used 50 mpg for a hybrid-electric vehicle. For all the vehicles—and everything else you see in the table below—your mileage may vary. Drive less and drive slower to get the most bang for the buck and for planet Earth. Gasoline and electricity prices are average U.S. retail from July 2010. The electricity rates are averages tracked by the Department of

## Dollar Cost of Driving 15,000 Miles

Location	Electric Car	50 MPG Hybrid Car	30 MPG Gasoline Car
<b>Phoenix</b>	\$491	\$816	\$1,360
<b>San Francisco</b>	647	936	1,560
<b>Boulder</b>	490	801	1,335
<b>Miami</b>	487	792	1,320
<b>Boston</b>	613	804	1,340
<b>Detroit</b>	529	828	1,380
<b>Nashville</b>	397	756	1,260
<b>Houston</b>	500	777	1,295
<b>Seattle</b>	345	897	1,495
<b>Washington, DC</b>	593	840	1,400

## Carbon Cost of Driving 15,000 Miles

Location	Electric Car	50 MPG Hybrid Car	30 MPG Gasoline Car
<b>Phoenix</b>	7,335	7,110	11,850
<b>San Francisco</b>	4,345	7,110	11,850
<b>Boulder</b>	6,157	7,110	11,850
<b>Miami</b>	6,300	7,110	11,850
<b>Boston</b>	3,765	7,110	11,850
<b>Detroit</b>	7,725	7,110	11,850
<b>Nashville</b>	6,982	7,110	11,850
<b>Houston</b>	6,108	7,110	11,850
<b>Seattle</b>	3,690	7,110	11,850
<b>Washington, DC</b>	5,055	7,110	11,850

Energy—not special time-of-use rates that EV drivers may be able to take advantage of. The cities used are representative of larger regions. Remember: Electrons on the grid don't obey city or state borders.

Change the assumptions and you might get different numbers, but the regional pattern seems clear. As Professor Michalek said, "If you have a city where gasoline is expensive, and electricity is cheap and clean, it's a better fit for a plug-in vehicle than a city where gasoline is cheap and electricity is expensive and dirty." In a couple of those cities where electricity is especially dirty, the 50-mpg hybrid actually beats the electric car for low CO<sub>2</sub> emissions. At first, that surprised me, but I quickly came to see it as the exception that proves the bigger and more important rule: For a myriad of reasons—from less local air pollution to greater reduction of our dependence on oil—the pure electric car is as green and cheap as it gets.

—Brad Berman (brad@hybridcars.com), with thanks for help from Constantine Samaras of the Rand Corp.



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## on the web

To see details on my methodology and math, visit  
[www.plugincars.com/EVmath](http://www.plugincars.com/EVmath)



A large-scale solar power system is shown in a field. It consists of a large array of solar panels on a metal frame, a central grey battery unit, and a yellow generator unit. The background is a blue sky with clouds. In the bottom left corner of the image, there is a small text box that reads: "QUALITY SYSTEM CERTIFIED TO ISO 9001 ISO/TS 16949 ISO 14001".

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Courtesy Exeltech

## Transformerless PV Inverters Introduced by Exeltech

In early 2010, **Exeltech** introduced their XLGT transformerless inverter ([www.exeltech.com](http://www.exeltech.com); MSRP \$1,300). This 1.8 kW inverter is listed by the CEC as 96.6% efficient. The transformerless design keeps the weight down to 14 pounds—one person to lift and mount it. The inverter is enclosed in an NEMA 3R enclosure, suitable for indoor or outdoor locations, and has a built-in AC/DC disconnect. Inverter DC input ranges from 200 to 600 VDC, and output is 120 VAC. There is no digital metering included with this inverter—status is displayed by an LED light.

A white, compact refrigerator unit with a blue top and a blue umbrella nearby, set against a backdrop of palm trees and a beach. A speech bubble from the unit contains promotional text.

Along the serene, deep-blue waters of the Caribbean on the beaches of Puerto Rico, Raúl Rosado uses power from the sun to prepare cold, refreshing drinks for his customers. Raúl uses a SunDanzer refrigerator and solar PV to make cold anywhere he goes using only free, available sunlight. To learn more about SunDanzer DC-powered refrigerators and freezers, including our new ultra efficient upright unit and our easy-to-use battery-free unit, contact your solar products dealer or find us online at [www.sundanzer.com](http://www.sundanzer.com).

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## and SMA America

**SMA America** is now offering their TL-US line of 8, 9, and 10 kW transformerless inverters for the U.S. market ([www.sma-america.com](http://www.sma-america.com)). The 8 and 9 kW inverters have a CEC-listed efficiency of 98%; with the 10 kW model at 97.5%. Each inverter weighs 77 pounds, has a NEMA 3R enclosure and DC disconnect. These inverters include an external six-string combiner box, which allows for fusing on both the positive and negative conductors for ungrounded three PV input strings. With a 208 VAC nominal output, this inverter is made specifically for commercial, three-phase utility interconnection, and cannot be used in residential 120/240 VAC systems. DC input voltage ranges from 300 to 600 VDC. There is a digital meter included, with optional RS485 and Bluetooth interfaces. The 10-year standard warranty is extendable to 15 or 20 years.

Like all transformerless inverters, these Exeltech and SMA inverters require that neither PV input current-carrying conductor be grounded, and follow NEC requirements for ungrounded arrays (see *Code Corner* in HP139).

—Justine Sanchez

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# Art-Tec Solar

## Differential Temperature Controller



A differential control for PV-powered solar hot water systems enhances system efficiency by making sure the pump runs only when collector temperature is high enough to add heat to the storage tank. Art-Tec's DTC-D controller ([www.arttecsolar.com](http://www.arttecsolar.com); MSRP \$200) has basic differential control functions along with a few added features. The control has digital display of the sensor readings and minimum and maximum temperature settings—the differential is field-settable. Four included NiMH AAA rechargeable batteries will keep the control operating for 48 hours without PV power. The control also incorporates a high limit for maximum tank temperature and has an audible alarm. A recirculation setting for extremely mild climates rounds out the main features (this also has an audible alarm). The system must have a battery for the recirculation feature to energize the pump. The control is protected by an internal surge suppressor and 6-amp fuse. The DTC-D uses standard 10 K sensors. The control operates with a 12 V nominal PV module, but will control either 12 or 24 V pumps. Art-Tec has two other DC controllers available with fewer features.

—Chuck Marken

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# The Twitter REffect

If you haven't already created a Twitter account, then now is the time. This social-networking craze is here to stay, and it's bringing RE enthusiasts closer together—one "tweet" at a time. Twitter has a growing RE community. No matter what you are trying to keep up with, Twitter has a lot of information— incentives, legislation, special offers, product innovations, DIY techniques, and virtually anything you can imagine.

For those who are new to the world of Twitter, here's the gist: Twitter is a microblogging platform for publishing short messages (less than 140 characters) through different media, such as instant messages, cell phones, and the Web. Links to pictures, videos, and articles can enhance the value of each tweet. These messages can be shared with select group or made publicly accessible on [www.twitter.com](http://www.twitter.com). Once you set up a free account, you can choose your favorite "tweeps" to follow, and check out and enter into virtual conversations via your computer or mobile device.

The key to a rewarding Twitter experience is finding good tweeps. Below are a few to get you started, but we encourage you to explore the Twitterverse on your own. To find these

folks, just replace the username after the end of the website address: [www.twitter.com/username](http://www.twitter.com/username).

**HomePowerMag** • Of course we're going to toot our Twitter here—it's a great way to keep up with us on the run. Get links and ideas and tap into tweets from the *Home Power* crew.

**100kHouse** • For frugal, common-sense innovations, follow the pithy banter from the folks at PostGreen, a Philadelphia-based group that is building a LEED Platinum home.

**AWEA** • The American Wind Energy Association strives to expand the use of wind energy and reduce windy industry market barriers. Tweets cover what they are up to, along with other wind energy items of interest.

**BestGreenBlogs** • Instead of trying to monitor all the green blogs from around the world, follow this feed for their version of the best of the best. Topics run the gamut, from DIY solar hot water and biodiesel projects to recycling and farming.

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**energystar** • An official feed from the DOE's Energy Star program with the latest product ratings and home improvement tips.

**greentweet** • Follow the politics and practice of sustainable living with this feed from Chelsea Green Publishing. The company publishes top books on sustainable living—they

know of what they tweet and often include helpful tips on living sustainably.

**RhoneResch** • As president of the Solar Energy Industries Association, Resch has his finger on the pulse of the industry, often tweeting links and items that affect the industry. (To keep tabs on activity in your state, find the Twitter feed of your regional SEIA chapter.)

**solarenergyintl** • The Colorado-based nonprofit has its own Twitter feed, providing updates on RE training opportunities throughout the country and around the world. Tweets are on news, advances, and more.

**SolarFeeds** • Scott Weitzman maintains a large solar news network. He tweets, retweets, and follows all things solar, pulling from more than 275 contributors who cover solar news, products, and stocks.

—Kelly Davidson

## New to Twitter?

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*The Twitter Guide Book* • [www.mashable.com](http://www.mashable.com)

*Twitter 101* • [www.twittercism.com](http://www.twittercism.com)

*The Beginner's Guide to Twitter* • [www.michaelhyatt.com/the-beginners-guide-to-twitter.html](http://www.michaelhyatt.com/the-beginners-guide-to-twitter.html)

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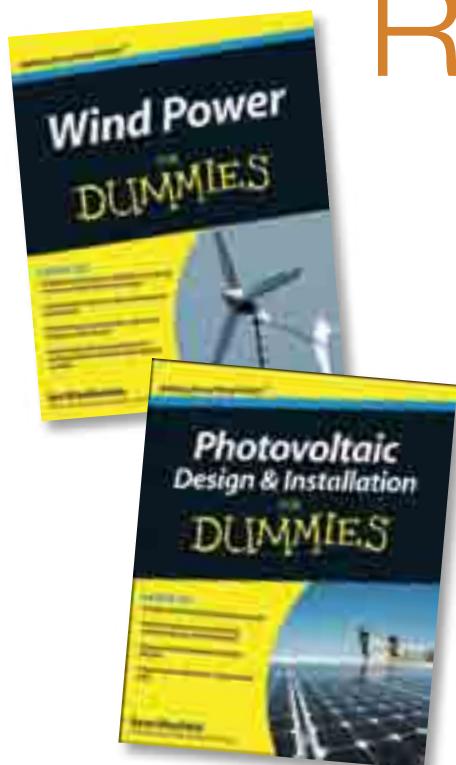
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# RE for Dummies

From *Home Power* senior editor Ian Woofenden and contributor Ryan Mayfield come two new titles in the *For Dummies* series. Designed to be quick reads with easy-to-replicate examples, these books offer trustworthy, step-by-step guides to wind power and solar-electric systems.

If you're looking for home-scale wind energy, *Wind Power For Dummies* from Ian Woofenden is the book for you. Woofenden will lead you along the path to wind power—from picking, setting up, and working a small-scale wind generator to collaborating with contractors and complying with local zoning laws. His emphasis on safe, practical applications of wind power will make a solid addition to your RE bookshelf. Once you reach the last page, you'll be ready to embark on your wind-powered future.

On the solar side of the RE spectrum, Mayfield's *Photovoltaic Design & Installation For Dummies* caters to a variety of audiences—whether you're a homeowner interested in a home-scale solar-electric system, an energy professional looking for work in the PV field, or an installer studying for the NABCEP certification exam. From the basics, like site selection and the physics behind the earth-sun connection, all the way to specific modules and safety techniques, this title will increase your PV vocabulary and develop your RE skills.

—Kelly Davidson

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# Energized Education

Like many Native Americans of his generation, 31-year-old Dean Davis lived on a reservation without electricity or running water for much of his early childhood.

"We lived in a beat-up, one-room house. We carried all of our water from a nearby stream and relied on a wood stove for cooking and heating," recalls Davis, who grew up on the Menominee Indian Reservation in Neopit, Wisconsin.

It wasn't until the late 1980s that Davis and his family moved into a house that had modern conveniences—like refrigeration and indoor plumbing. Their situation was not uncommon for the times.

"Life was simple. We didn't have a lot of material possessions. And energy concerns—where it came from, how much it cost, or when it would run out—were not a part of our life," he added.

A lot has changed since those days. Davis, an ex-marine who served as a diesel mechanic in Afghanistan, is very much aware of the energy issues affecting the world today. He is now studying microcomputers at the College of the Menominee Nation and doing his part to bring clean energy to his tribal lands.

Davis is somewhat of a local hero since his name appeared in the newspaper last year for placing in the annual Indian Education Renewable Energy Challenge—a national contest sponsored by the Office of Indian Energy and Economic Development, the Bureau of Indian Education, and the U.S. Department of Energy's Argonne National Laboratory (ANL).

"People around campus and in the community seek me out and ask me questions about all sorts of energy projects," Davis says. "The contest has opened many doors for me and definitely opened my eyes to what is possible with renewable energy."

**Dean Davis, on campus with his wind turbine prototype.**



Courtesy ANL

Now in its second year, the competition calls on tribal students to construct a renewable energy apparatus from scratch. Teams first submit design proposals. From those submissions, five high school and five college teams are chosen to receive \$3,500 to build prototypes of their designs.

Teams are judged on detailed reports and step-by-step videos that document the design process and demonstrate the prototype in action. Prizes are awarded at both the high school and college levels.

"The competition is a great way for students to translate what they are learning in the classroom to real-world applications for developing renewable energy sources," said Harold Myron, director of Argonne's educational programs division.

Dave Santee, a special education teacher in sciences at Oneida Nation High School in Oneida, Wisconsin, says the challenge is to help break the stigma that tribal communities can't compete in sciences. A group of students from his school designed and built a wind turbine that took first place in the high school category last year.

"When we take the theoretical and put it into the practical, we see the students really engaged and feeling empowered," he says. "It all clicks. They see that the use of renewable energy complements our beliefs—our respect for the environment and our concern for future generations—and they begin to understand how renewable energy can be used to improve the quality of life in tribal communities."

John Big Medicine, a 20-year-old senior at the high school, helped design the blade for his team's winning turbine. While he's still not sure what career path he wants to follow, he says the experience sparked an interest in renewable energy.

"Working as a team on the wiring and blade design was the most rewarding part of the experience," Big Medicine says. "We made the blade out of balsa wood, and ended up carving the wood thinner on bottom and thicker on top, but that idea developed as we worked together and brainstormed different methods."

At the college level, the prototype that Davis constructed last year tied for first place with a design created by students from the Southwestern Indian Polytechnic Institute in Albuquerque, New Mexico. Davis led the design and construction of a portable wind turbine that simultaneously converts wind and water to electricity to power LED lamps. He learned of the competition from one of his professors, who encouraged him to develop a proposal as a part of a sustainable development course. In 2011, he hopes to repeat his top performance. Davis has submitted a design proposal for this year's competition. (Note: At the time of press, the finalists had not yet been selected.)



Courtesy ANL

**Students get hands-on experience with RE systems through the annual Indian Education Renewable Energy Challenge.**

The goal of this year's competition is to develop a process that converts biomass into diesel fuel. The competition is part of a federal initiative to recruit and train the next generation of tribal energy professionals. ANL also hosts 10-week-long summer internships at its campus in Illinois. The highly competitive program has only 12 openings each year, and is offered only to Native American students from public, private, and tribal institutions of higher learning. Once accepted, students select an area of study and spend their

## From Energy Impoverished to Energy Empowered

Today, more than 14% of Native American households on reservations have no access to electricity, compared to 1.2% of all U.S. households. And those who do have electricity often pay significantly more in home energy expenses than other U.S. households, according to a 2010 report.

A 2010 report from the National Wildlife Federation—*The New Energy Future in Indian Country*—found that tribes are disproportionately shouldering the burden of climate change, yet have “vast potential” to mitigate further damage by generating clean energy from renewable resources like solar, wind, biomass and geothermal.

One of the key steps to realizing that potential is growing a workforce that is skilled in those technologies. The Office of Indian Energy and Economic Development is working to address that challenge, and help Native Americans manage their energy opportunities. To learn more, visit [www.bia.gov](http://www.bia.gov).

Another resource is the Tribal Energy and Environmental Information Clearinghouse ([www.teeic.anl.gov](http://www.teeic.anl.gov)), which provides information about energy resource development, and associated environmental impacts and mitigation measures.

## Native Energy Potential

The energy potential of Native American lands is large. There are 565 federally recognized tribes in the United States. These tribes own and manage more than 95 million acres of land across the nation—11 million more than the National Park Service and almost 5% of the total area of the United States. According to the U.S. Department of Energy's Tribal Energy Program, those lands hold an estimated 10% of the country's resources, including the potential for 535 billion kilowatt-hours of electricity per year from wind power. Solar has even greater promise, at 17 trillion kWh per year—the equivalent of 4.5 times the total national energy generation in 2004, according to the U.S. Department of Energy.

days working alongside professional researchers on energy-related projects.

The nature of the internships runs the gamut—from climate change and hydrogen storage to the production of chemicals from renewable resources. For example, one student of the Confederated Salish and Kootenai tribes came from the University of Montana to conduct laboratory research in using solar energy to convert carbon dioxide to fuel.

A Navajo student from Utah Valley University chose to do field work in micrometeorology and ecological sciences to determine the pathways of solar energy within the prairie vegetation and soil. A Seneca Nation student from Syracuse University evaluated the costs and environmental impacts associated with developing solar energy facilities on tribal lands in six western states.

“Our mission is to inspire and educate our nation's future scientists and engineers,” says Tony Dvorak, director of Argonne's Environmental Science division. “Many tribes struggle with poverty and soaring unemployment. The ultimate success is that each student takes what they've learned back to their tribal lands and help grow new energy economies that will create jobs and revenue opportunities for their communities.”

Davis is doing just that. In addition to his microcomputer studies, he is working with the tribal conservation department to develop a water filtering system that will help prevent an invasive plant species from spreading into area streams and assisting a local councilor in helping the community reduce its energy use and costs.

Inspired by his big win from last year, Davis also founded a renewable energy club on campus and prepared a submission for the annual P3 awards, a student sustainable design competition sponsored by the U.S. Department of Environmental Protection that focuses on people, prosperity, and the planet.

—Kelly Davidson

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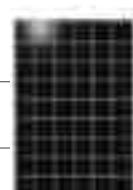
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## Time-Saving, Rail-Free Mounting

After years in the solar industry, ASC Solar Solutions President and Head of Design, Michael Muccio, was looking for a more streamlined process for PV array installation—and he found Zep.

Conventional roof racks mount PV modules on top of rails (which are secured to the roof on mounting feet). Zep Solar's rail-free mounting system uses modules with frames that have an integrated groove, and adjustable leveling feet that mount to the roof.

Muccio's first opportunity to use a Zep mounting system came when Steve Hiecklen, owner of Jersey Pools & Spas in Medford, New Jersey, wanted to have a 50 kW system installed at his business (a 10 kW system will also be installed at his residence).

A groove in the frame of Canadian Solar Panels' New Edge line is designed for the Zep System II. Modules are coupled together with Zep's interlock devices, which seat into the groove, providing both structural support and ground-bonding. Zep's adjustable leveling feet provide attachment to the mounting surface or flashed attachment.

ASC Solar Solutions installer Chris Searles says there was about a two-hour learning curve to determine the array layout and get used to the Zep tools. Once this was accomplished, the install went fairly smoothly. Because the roof was not perfectly level, leveling and interlocking modules was challenging. Additional comments included that roughly 20% fewer roof penetrations were required than for a conventional mounting system.

To date, Muccio's team has completed the largest installation of the Zep System II. They estimate that this array was installed about 30% faster than ones that use a conventional racking system and that with some practice, time savings could be up to 40%.

—Michael Tuman

### Project Specs

**Project name:** Jersey Pools & Spas

**System type:** Grid-tied PV

**Installer:** ASC Solar Solutions

**Date commissioned:** September 2, 2010

**Location:** Medford, New Jersey

**Latitude:** 39.9°N

**Resource:** Solar

**Average daily peak sun-hours:** 4.5

**System capacity:** 49.7 kW STC

**Average annual production:** 61,000 AC kWh

**Average annual utility bill offset:** 97%

### Equipment Specs

**Number of total modules:** 216

**Manufacturer and model:** Canadian Solar CS6-230

**Module rating:** 230 W STC

**Inverters:** 6 SMA 7000; 2 SMA 5000

**Inverter rated output:** 7,000 W; 5,000 W

**Array installation:** Rooftop

**Roofing material:** Composite shingle roof

**Array azimuth:** Subarrays oriented at 166° (40.94 kW) and 249° (8.74 kW)

**Tilt angle:** 24°; 14°

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# Estimating Obstruction Height

The fuel for a wind generator is moving air, and its energy content increases cubically as wind speed increases. So for good performance, it's vital to get wind generators up into the powerful, nonturbulent winds.

To be effective, wind generators need to be sited well above nearby obstructions. One common rule in the small wind industry is to make sure that the lowest blade tip is *at least* 30 feet above everything within a 500-foot radius.

To decide on tower height, you must know the height of nearby obstructions, be they hills, trees, or buildings. There are several methods to determine these heights.

## Climbing & Measuring Method

Perhaps the most obvious method of determining the height of an obstruction is to measure it directly. This is often not possible or practical, but when it is, why not do it? Climb to the roof of the building or up the tallest tree, carrying a long tape measure. With an assistant on the ground, you can get a very accurate measurement.

In the case of a tree, you can climb with the tail of the tape attached to your harness. You won't be able to climb to the very top, but you'll be able to estimate the distance above you when you reach as high as you can go. Remember to do the research to understand what the *mature* tree height will be, since this will be important to your tower height as trees grow over the years.

While you are at that measured high spot—be it building, tree or hill—you can use a site level to gauge other nearby obstructions. Once you have a baseline measurement from your high location, you'll be able to make a reasonable guess of the height of other tall things nearby. Some perspective from an on-the-ground helper may help: "...if you're at 80 feet, that tree over there must be about 95 feet tall..."

## Inclinometer

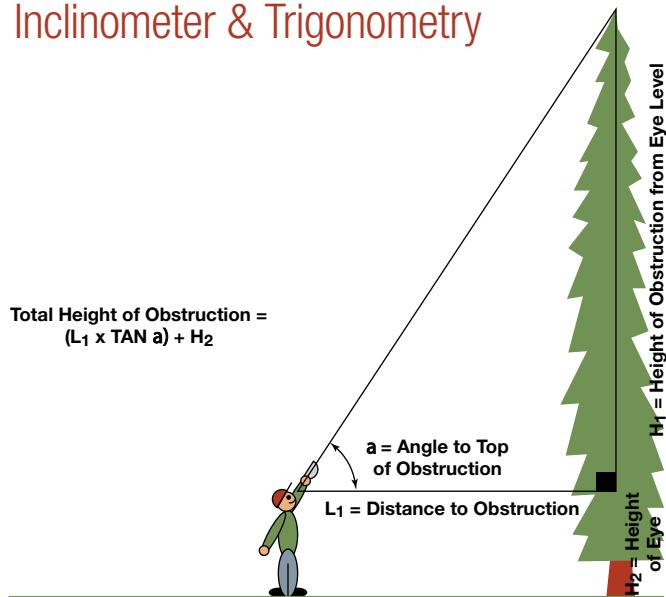
An inclinometer is a device that measures angles of inclination and costs \$100 to \$300. You sight through it at an object, and the tool tells you what angle from level your sight line is. A low-budget alternative is to use an inexpensive angle gauge attached to a yardstick, which you can sight up.

With the angle formed by the ground and this sight line, a bit of measurement and math can tell you an obstruction's height:

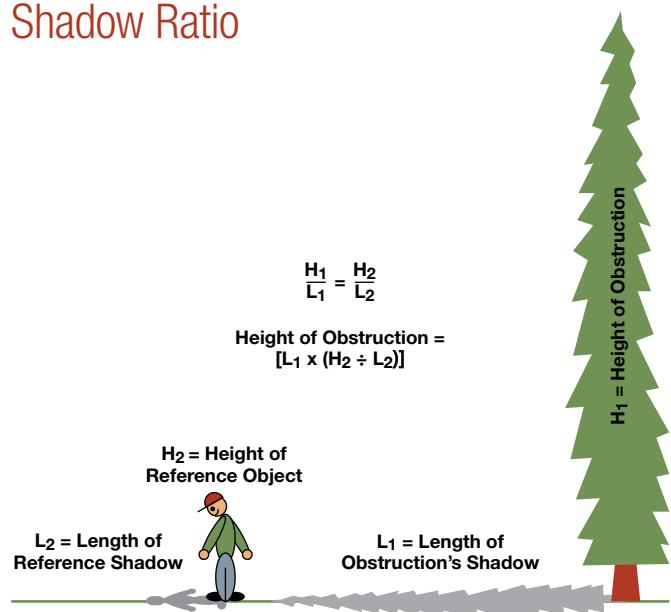
- Measure the level distance from your inclinometer reading spot to the obstruction.
- Find the tangent of the angle—scientific calculators have this function, and some inclinometers will give you a read-out in the tangent of the angle.

**Obstruction height = height of your eye above the ground + (distance to obstruction × tangent of angle)**

## Inclinometer & Trigonometry



## Shadow Ratio



## Shadow Method

A simple method that doesn't require any complex or expensive gear is useful when the obstruction casts a clearly measurable shadow. First measure that shadow length at a specific time of day. At the same time of day, measure the shadow of an object of known height. Then do the math to calculate the height of your obstruction.

For example, if a 6-foot-tall fence post casts a 10-foot-long shadow, you know the ratio between the post height and its shadow length. If the obstruction in question casts a 100-foot-long shadow, you can use the ratio to calculate that the obstruction is 60 feet tall.

## Stick Methods

You can use a stick held vertically in front of you at arm's length. Hold the stick with your thumb and a finger near the bottom, and adjust the stick so that when you sight with one eye, your thumb marks the base of the obstruction and the top end of the obstruction is at the top end of the stick.

Measure the stick height (using a yardstick helps) and the length of your arm (the distance between the stick and your eye), and you can calculate the obstruction height with this formula:

**Obstruction height = distance to the obstruction × stick height ÷ arm's length**

Another method is to use the stick just as in the previous method. After you've sized up the tree with it, simply tip the stick sideways and put one end so it appears to be at the base of the tree. Note where sighting across the other end of the stick shows up on the ground parallel to the tree, and have a second person measure from the base of the tree to that location. This works best with level ground.

## 45-Degree Method

Basic geometry tells you that a right triangle (90° angle at one corner) with two equal-length sides will have 45° angles at its other two corners. A simple application of this can quickly get you the height of an obstruction. The 90° part of the triangle will be the tree, relative to the ground. Stand back from the obstruction and point at it, holding your arm at a 45° angle. You can use a tri-square with level, an angle gauge or a smartphone app to gauge the correct angle.

Move back until your angled arm is pointing at the top of the obstruction, and you will be about the same distance from the obstruction as its height. If you want to get exact, run your 45° angle down from your eye to the ground behind you, and then measure from that point to the base of the obstruction.

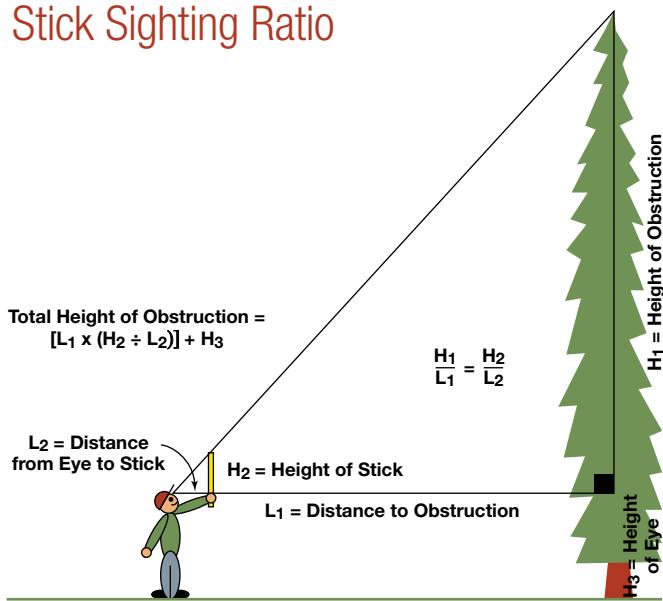
Smartphone users might want to tap into high-tech applications like Smart Measure for Androids and DAH-Measure for iPhones. These apps use the smartphones' cameras and level sensors for input and then calculate height for you.

## Interpreting & Rounding

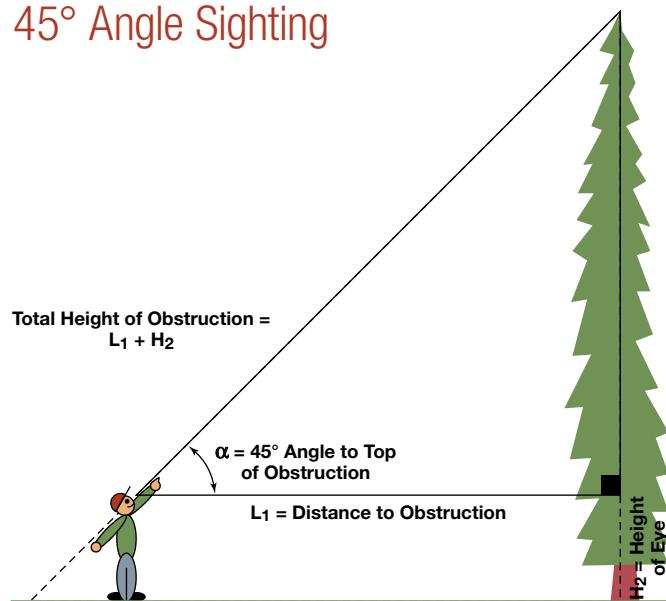
Any of these methods will give you an idea of the height of the obstructions within range of your proposed wind generator. How exact the measurement is will depend on which method you use and how carefully you apply it. But precision is not necessary, since you should round up generously anyway. The two most important words in the 30/500 rule—site wind generators at least 30 feet above anything within 500 feet—are “at least.” Higher will always be better.

—Ian Woofenden

## Stick Sighting Ratio



## 45° Angle Sighting

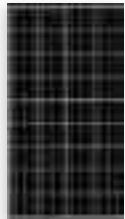


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## Battery Basics

Allan Sindelar is to be commended on writing an excellent primer on off-grid batteries ("Off-Grid Batteries: 30 Years of Lessons Learned" in *HP140*). I find that most of what my customers *think* they know about batteries is incorrect. Consequently, I apply the largest markup of any product I sell to all batteries. In this way, I cover the cost of all the phone calls and site visits so I don't have to bill them for years.

With luck, at least some of my clients will learn enough to maximize the life span of their expensive new batteries. I have a number of customers with 20 years or more on their investments. Left to their own devices, they would just buy a truckload of 6-volt golf-cart batteries, wire them in many parallel strings, ignore the maintenance—and have to change them out every four years. Your article will be very helpful in their education.

If I've learned anything at all, it's this: buy the largest single series string of 2-volt forklift type cells, *shallow cycle* them, and make sure they get *fully charged* on a regular basis.

My grandfather always said, "It's not what you don't know that makes you ignorant, it's what you think you know that's incorrect!" That's my 2 cents' worth—thanks again.

Nick Houser,  
Off Grid Services •  
Powell River, British  
Columbia, Canada

## Kudos & Comments

It was thrilling to see pictures from the Gaviotas ecovillage ("Gaviotas—Building a Sustainable Community" in *HP140*). I've been a fan of this community since Alan Weisman spoke at the Midwest Renewable Energy Fair in 1998. Since then, little news of Gaviotas has made the media, so I thank Laurie Guevara-Stone for her fine article. I wonder if medical care is still available in or near Gaviotas now that the hospital has become a bottling plant.

Great myth-busting was done by Dominic Crea's "Motion Myths" article, and by Tom Simko's letter about a new Idaho windmill start-up company that has claimed efficiencies exceeding the maximums possible according to physics. Here in Michigan, there have been several microturbine start-up companies with similar inflated claims. Some got ARRA funding due to the large number of "green"

jobs, yet neither the feds nor state bothered to vet the technology—which typically includes mounting the turbines close to the ground, equivalent to putting solar modules in the shade. I've yet to see "science-based governing."

Ian Woofenden's "Working Bikes Cooperative" article points out that we can put some sweat equity into our trips and energy needs—and get better health in the bargain.

Ian's "Off-Grid Appliances" article was on target with tips relevant to on-grid efficient appliance selection, too. At my house, we have both kinds of DC refrigerators he mentioned; we use DC motors for loads that run for long periods or frequently, thus letting our inverters sleep as much as possible. Here's a principle of food refrigeration that's independent of power source: our chest-style refrigerator does a better job at preserving food longer than the upright can do, and with less energy. We've found that in refrigeration units that are opened a lot, it is difficult for an upright to maintain stable temperatures. Every time the door opens, cold air pours out and is replaced by warm air, and convection between the vertical surfaces that are at temperature extremes keeps exchanging the heat energy, even when closed.

One recommendation for laundry energy savings factor is not found on the Energy Star website—the washer spin-cycle speed. Most laundering energy is spent in the dryer, and there is little difference in dryer efficiencies. Spin extraction, typically done by the washer, takes far less energy and can also be done by a relatively low-cost (swimsuit) spin extractor. This worthwhile energy investment is good even for hand laundering and line drying, since it speeds drying and keeps excessive humidity out of the house. Most Energy Star washers don't have spin speeds above 1,100 to 1,400 rpm, but Asko makes one model that reaches 2,000 rpm quietly and safely, and the spin extractors can reach 3,000 rpm. Follow the manufacturer's instructions carefully with spin extractors, because such high speeds can be dangerous.

The ultra-efficient *passivhaus* design typically doesn't use a clothes dryer appliance, whose vent duct constantly loses heat and unbalances the air-pressure in a tight home. Instead, a drying closet is located at the exhaust line of the recovery ventilator ducts, so that stale air leaving the house picks up moisture from the clothes before it exits, hastening the drying process, while recovering much of the energy in the warm, humid air.



Courtesy US Battery

Thanks again for a wonderful collection of articles!

Christina Snyder, architect  
& Certified Passive House Consultant •  
Manchester, Michigan

## Hydrogen Myths

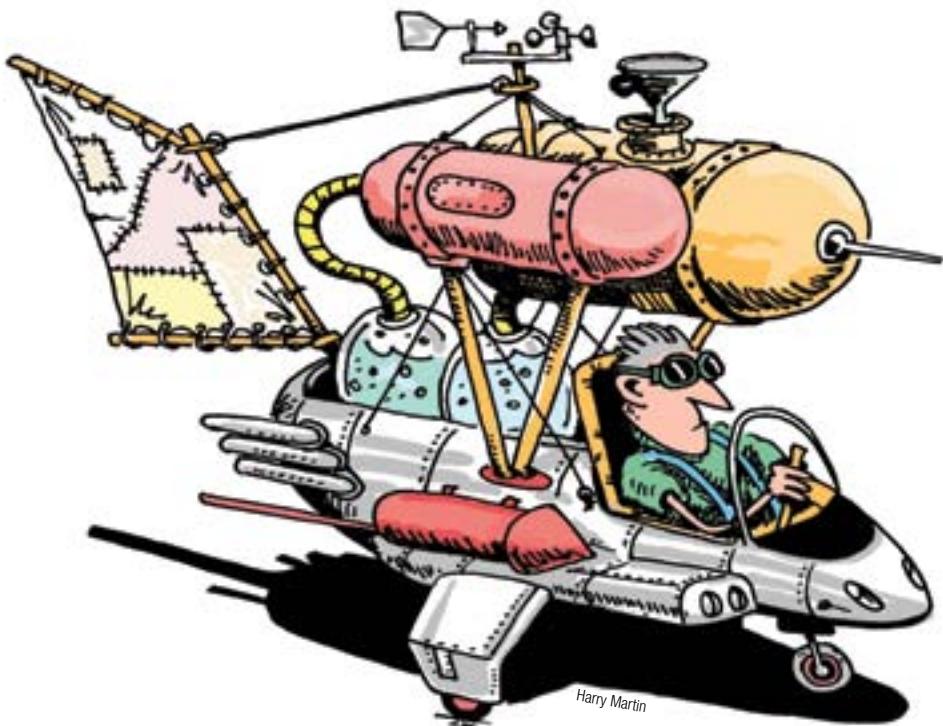
Thank you for Dominic Crea's "Myths in Motion" in *HP140*, which debunked the idea of using a hydrogen generator to increase gas mileage. This certainly is a myth that needs debunking, but the article missed the crux of *why* it doesn't work.

The article states that the problem with the concept is with processes that are less than 100% efficient: "...the faulty premise lurking in this myth is centered on alternator efficiency and that of all subsequent processes..." and "...of the energy that could have been used to power the car directly, something like 75% was wasted in these two steps alone."

Actually, that is not the problem with this concept. There is no net "energy that could have been used" and, if the processes referred to were 100% efficient, this concept still would not work. The real explanation of why this concept doesn't work is found on the following page of the article where the fallacy of perpetual motion machines is discussed—it is a violation of the first law of thermodynamics. The amount of "energy that could have been used" in this case has been borrowed from what the engine produced and would have otherwise gone to the drive train.

In a perfect world, assuming 100% conversion efficiencies everywhere, it takes 1 W of mechanical power from the engine to make 1 W of electrical power from the alternator to manufacture enough hydrogen gas to give 1 W of chemical power back to the engine to make 1 W of mechanical power. So what has been gained by jumping through all these hoops? Nothing.

I have found that people get tripped up in two areas in this case. The most common mistake is to think that the alternator makes a fixed amount of electricity all the time and if all of the electricity that is produced is not used, then there is some surplus electricity available that is otherwise wasted. This is not true. Alternators produce only what is demanded of them and, in turn, demand a corresponding amount of torque from the engine. The more electricity that the alternator is required to produce, the harder it is for the engine to turn the alternator. If you could attach a hand crank to an alternator, you could feel this. Every milliwatt of power called for when lights, radio, etc.



are turned on results in the alternator being harder to turn and the engine diverting a corresponding amount of power to turn it.

The other mistake is thinking that there is hydrogen gas (which contains chemical energy and is thus referred to as a fuel) available in water and that a small amount of electricity will free up an amount of hydrogen gas that contains more energy than the electricity required to free it. This is also not true. Water is not a fuel and there is no hydrogen gas in water, only hydrogen atoms.

Hydrogen gas can, however, be manufactured from the hydrogen atoms in water if energy is input through an electrolyzing process. Unfortunately this process is, once again, governed by the first law of thermodynamics. If all conversion processes were 100% equal, you get out only what you put in. Thus, 1 W of electricity would be required to produce enough hydrogen gas to contain 1 W of chemical energy. This is a net gain of zero. Now add real-world energy conversion losses and that zero gain goes to a net loss.

This concept fails because it violates the first law of thermodynamics—not because of less-than-perfect conversion efficiencies. Technology can improve efficiencies, but all that will ever do is make the net loss smaller.

Paul C. Glasser • Sherwood, Oregon

*Thanks for your comments, Paul. I would have liked to present the argument using the first law of thermodynamics, but my hope was to present an argument that would appeal to non-scientists. I like the way you presented it; thanks for the analysis.*

Dominic Crea

## Chevy Volt

Hello! I am a loyal subscriber to *Home Power*, and particularly appreciate the clean, clear, consistent layout, which is outstanding.

I do have a few quibbles with the article about the Chevy Volt ("Getting Charged Up with Chevy's Volt" in *HP140*). On page 56, one finds the often-stated, but inaccurate and misleading battery range of the car as "40 mile[s]", and at the same time, an accurate and contradictory statement to the effect that "the Volt uses 8.8 kWh of its total 16 kWh battery, at which point the generator comes on." This means that the car actually gets only 25 miles, maximum, from the unassisted battery, which should be clearly revealed, Chevy publicity notwithstanding. Nissan is much more forthcoming about the range—and its potential variability—of its Leaf.

Another thing that bothers me in general is the common assumption that electricity costs 10 cents per kWh, which I think is

well below the average in the United States. Taking all the monthly costs into consideration, I pay 15 cents per kWh. I know that in California, the prime-time rate can be as high as 39 cents per kWh. Of course, one plans to recharge the batteries at the most economical time, but this will not always be possible. Hence, I would advise being a bit more realistic about the cost of electricity.

Also, this possibly erroneous statement is made: "The 53 kW gasoline generator..." I do know that the electric motor in the Volt is 53 kW, but I doubt the onboard generator can put that much power out, nor would the batteries be able to accept that level of charging.

John F. Bundy • via e-mail

*General Motors says that the Volt's all-electric range varies from 25 to 50 miles (40 to 80 km) depending on terrain, driving technique, temperature and battery age. U.S. EPA tests determined that 35 miles was the nominal range in all-electric driving. However, Volt test-drivers have seen ranges*

*from 30 to 45 mpg in real-world driving conditions. You mention that the 8.8 kW usable battery capacity would only yield 25 miles of unassisted electric drive. While this may seem to be a reasonable assumption, it does not consider the regenerative braking feature that contributes a significant amount of energy to the system. The performance is very driver-dependent as it is in hybrid vehicles.*

*GM and the media in general tend to use that \$0.10 per kilowatt-hour figure as an average for the country and, admittedly, that information is a bit dated. According to a November 2010 U.S. DOE report, the current national average residential electric rate is \$0.12 per kilowatt-hour ([www.eia.doe.gov/electricity/epm/table5\\_6\\_a.html](http://www.eia.doe.gov/electricity/epm/table5_6_a.html)). Hawaii has the highest state average at \$0.28 and Washington state has the lowest at \$0.08.*

*GM has stated the capacity of the 1.4L 80 hp engine generator is 53 kW. This capacity is required particularly in Mountain mode, in which the generator is maintaining a 45% battery state of charge and also*

*providing power to the electric drive while driving uphill. So yes, this is a very powerful generator as it needs to be to ensure reliable operation under all conditions. This was a central premise of GM's design philosophy.*

*Guy Marsden • Woolwich, Maine*

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## Concentrating Solar

In our Sintra, Portugal, house, we are already using a solar hot water system to heat our household water. We are thinking about installing a batteryless grid-tied PV system. If I understand correctly, achieving higher efficiencies (measured in multiples of suns) is possible by coupling a photovoltaic cell with concentrating optics. This combined system should require substantially less space to deliver the same amount of kWh as a normal PV module.

Is this type of system a viable alternative for residential purposes?

Silvio Berra • Sintra, Portugal

Concentrating solar for rooftop PV systems has always suffered from three fatal flaws—heat, cost and complexity. The rapidly declining price of crystalline silicon modules has placed the addition of optics even further down the ladder of choices. These systems require a tracking device to operate—the modules must stay perpendicular to the sun throughout the day. Tracking devices need additional parts for movement, adding complexity to an otherwise simple system that just sits in the sun and churns out electricity throughout the day. Occam's razor offers sound advice to RE folks as it does for

**This concentrating solar unit with integrated tracking has 24 modules, each containing 12 series-connected PV cells. Note: Two units are shown. Each unit is rated at 330 watts.**



Courtesy Morgan Solar

scientists—the simplest system is usually the correct one.

A focusing system will only work well under full-sun conditions. During periods of diffuse sunshine, it will hardly produce electricity, if

at all. In contrast, your stationary PV system will generate energy even with cloud cover. Optical systems do not just concentrate the light, they also concentrate the heat. As is well known, PV cells do not operate as efficiently when they are hot, and may also be subject to damage from the heat. So it becomes necessary to remove the heat from the cells—a difficult task.

Concentrating modules don't necessarily take up less space, since the size of the optics is the determining factor, not the size of the cells. If greater electrical production per area is your concern, I would suggest purchasing the higher-efficiency modules.

That said, it would be foolish to say "never" and to dismiss optics for future rooftop PV systems. For example, using non-imaging optics that guide photons to modules eliminates the need for tracking. They work like light funnels: light enters from a large space and is passed to a smaller area. Focusing light onto spectrum-splitting multijunction cells could result in modules that are 50% efficient. Allen Barnett, the team leader in developing such a device, says, "I think the utilization of [PV technology] is in its infancy." Perhaps we'll see future advances where optics would be the best choice for rooftop PV systems, but today, your high-efficiency crystalline module—with plenty of air space in back to keep it cool—would be the best choice.

John Perlin • Dept. of Physics,  
University of California, Santa Barbara



Courtesy Whitfield Solar

## Overhang Dilemma

I'm in the process of designing my passive solar home and am struggling with figuring out the best overhang depth for the south-facing windows—one that allows ample solar gain in the winter, but prevents excess solar gain in the summer. I've done some modeling, and no fixed overhang seems to do the job quite right. Should I just aim for the middle and then use some sort of retractable awning or seasonal shading system instead?

Christie Mills • Huntsville, Alabama

There's a common myth that fixed overhangs are an effective way to control unwanted solar gain through south-facing windows in the summer, but fixed overhangs are not that effective.

The reason is that, in the summer, the sun is high in the sky. At this indirect angle, very little direct solar radiation hits a south-facing window and most of it is reflected away. Most of the solar energy that enters a home's south-facing windows in the summer comes from diffuse radiation from the southern sky and from light that reflects off the ground. An overhang does little to block these sources.

Effective control of unwanted solar gain in the summer, spring and fall requires movable devices like blinds, curtains and adjustable awnings. The further advantage of movable devices is that they involve the people in the home in attuning to the seasonal and daily patterns of the sun. We get to be part of the natural system!

Trying to remedy excess summertime solar gain by deep overhangs alone also has another disadvantage, since they will likely block valuable solar energy when the sun is lower in the sky in spring and fall. In the heating season, a greater proportion of solar radiation comes directly from the sun because it hits the window more directly. A practical roof overhang above a south-facing window should be from 8 to 16 inches deep. I recommend that *Home Power* readers look at my report on this subject; it can be downloaded at [www.cede.psu.edu/users/alau/OverhangASES98.pdf](http://www.cede.psu.edu/users/alau/OverhangASES98.pdf).

Andy Lau • Associate Professor of Engineering, Penn State University

In cooling-dominated climates like yours, where direct solar gain means longer air-conditioning run times and discomfort, *properly sized* overhangs can be a valuable strategy for keeping solar radiation from penetrating the building envelope. It is easier to protect against solar gain externally (with



**Appropriately sized overhangs can help mitigate some of the effects of summertime heat gain. But beware of ones that are too deep, which can block out too much sun in the winter, when the passive solar gain is wanted.**

overhangs, shutters or adjustable awnings) than internally (with blinds or curtains).

Proper overhang design considers sun angles, local climate and window placement, and is one piece of the puzzle for passive solar design—an important yet imperative first line of defense against unwanted heat gain in the summer and good gain in winter. In your location, you'll want to examine your heating and cooling degree days, and determine when you want the sun to come in and when you want to keep it out. (A good—and free!—online program to determine overhang depth can be found at [www.susdesign.com](http://www.susdesign.com).)

However, there are other considerations. In the early morning and late afternoon, overhangs will largely be ineffective, and the low-angled sun will be able to enter through windows. There are several ways to address this. Externally, shading structures,

such as fins or trellises, can shade windows. Strategically planted vegetation can also screen out unwanted sun. But internal systems, such as using insulated window shades, can also be very effective. Although blinds and curtains are often viewed as "interior design" elements, they can serve an important function in maintaining comfortable indoor temperatures and reducing energy consumption.

I think the goal for many passive solar home designs is to get more than halfway to energy independence with smart design—proper orientation, overhangs, south-facing windows, thermal mass, super-insulation, low air leakage, etc. Follow that up with smart technology—and even hands-on deployment of movable shading devices like blinds and screens—and most of us can drastically reduce our energy footprint.

Rachel Connor • Solar Energy International

## Rooftop Hydro?

My crazy idea—to use runoff from my roof to generate electricity—involves collecting the runoff in 55-gallon rain barrels. I'd meter the flow out of them with a valve that shoots a stream of water, which turns a DC generator and charges a battery bank. I live in the Seattle area, where we have plenty of rain. What should I consider as I plan this?

John Fischer • via e-mail

Unfortunately, there is not enough rooftop water flow to make this worthwhile, even in rainy areas like Seattle. Although it rains a lot of the time in Seattle, there's not much actual accumulation. Seattle averages about 37 inches of rain every year, significantly less than I get even in northern coastal California.

Here is a common way of estimating the power available in a home-scale water source:

**Gallons per minute (gpm) × feet of vertical drop (head) ÷ 13 = watts**

Say you have, for example, 5 feet of head from the rain barrel to the hydro turbine. If you fill up your rain barrel, and run it all into the hydro turbine at the rate of 55 gallons per minute, here is the power:

**55 × 5 ÷ 13 = 21 watts**

If you could run that continuously, you'd get about 1/2 kWh over 24 hours. But at 55 gpm, you'd drain your rain barrel in 1 minute, which is 1/60 of an hour. So every time the rain barrel is filled and then emptied through the hydro turbine would result in 0.35 watt-hours (21 × 1/60).

Then you need to figure out how often you can do that, considering Seattle's rainfall. For every 1,000 square feet of catchment area, about 620 gallons of water for every inch of rain can be collected. Let's assume a collection area of 1,000 square feet.

**620 gal. per in. × 37 in. per yr. = about 23,000 gal. per yr. ÷ 55 gal. per barrel = 418 barrels per yr.**

**0.35 Wh per barrel × 418 barrels per yr. = 146 Wh per year**

That is not a lot of energy, considering the average U.S. household uses about 11,000 kilowatt-hours per year. Also, it will be very expensive energy. Let's say you figure out how to get the equipment you need dirt-cheap, at \$500. Assuming a 20-year equipment lifetime, that still computes to about \$170 per kWh, about 1,000 times the

national average for utility electricity. (2,920 Wh generated in 20 years.  $500 \div 2,920 \text{ Wh} = \$0.17 \text{ per Wh}$ ;  $\times 1,000 \text{ Wh/kWh} = \$170$ .)

The "collector area" of a typical hydro system is measured in square miles of watershed. And it's common to find heads of 30 to hundreds of feet in these systems. Your rooftop has a collector area of square feet, and only a few feet of head.

One of my colleagues once did some consulting for a large corporation in your city, with a very large office building that is 80 feet high. He calculated that a hydro system would only make about 1 kWh per day—about 10 cents a day in value.

Hydro is a powerful resource, but you need the two basic components—head and flow—in reasonable quantities to make it work.

Michael Welch • *Home Power* Senior Editor

## write to:

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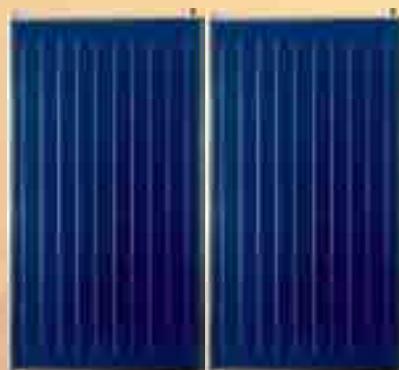
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# Solar Hot Water

by Chuck Marken



Luke Frazer of The Solar Collection in Talent, Oregon, with a closed-loop, forced-circulation, drainback solar hot water system.

Shawn Schreiner

## System Types & Applications

Federal, state, and utility incentives have spurred impressive growth in the U.S. solar hot water (SHW) industry in the last few years—and this demand has attracted many imports from Europe and China. While the basic systems haven't changed, imported and domestic innovations have altered traditional systems, and have even simplified installations in some instances.

The residential federal tax credits, and most state and utility incentive programs, require that SHW equipment be certified by the Solar Rating and Certification Corporation (SRCC), a private nonprofit organization that certifies solar hot water collectors and systems. Two protocols are specified: Operating Guideline (OG)-100 for collectors, and OG-300 for systems. Even if a collector or system is very simple, as some are, it must carry the SRCC certification to be eligible for those incentives. The SRCC certifications also give relatively new and somewhat longer names to all the systems—for instance, a batch water heater system is now referred to as an integral collector and storage system (ICS). These names are becoming the standard.

## System Types

On a sunny day, and when sized correctly, all of the collector types and systems can easily heat a storage tank to domestic hot water (DHW) temperatures. In Hawaii, where it never freezes, the open-loop, direct, forced circulation systems are the most popular. ICS and thermosyphon systems are popular in mild climates in the very southern parts of the United States. Most of the rest of the country uses drainback and antifreeze systems with preferences depending on regions and individual installers.

A quick method of sizing that works well for most residential systems is to have 1 square foot of collector surface area to every 1 $\frac{1}{2}$  gallons of water in the storage tank. In the Southwest, due to the increased solar resource, collector area is decreased to 1 square foot of collector area to every 2 gallons of storage water.

**Simple batch-style solar water heaters are relatively inexpensive and great for climates with little chance of freezing temperatures.**



Courtesy Chuck Marken

## SRCC Specifications

The SRCC lists hundreds of residential SHW systems.

The OG-300 system guidelines specify that the manufacturer supply the customer with operation manuals and instructions, and require that certain system components be labeled. The system specification also lists the manufacturer's recommended freeze tolerance level. OG-300 system

performance data has been integrated with climate data for hundreds of weather stations, and system performance estimates are available for many metro areas. Many states and utility districts use the SRCC estimates to compute incentives for SHW systems.

SHW systems are separated into two main types:

**Open-loop** is a system that circulates potable water through the solar collector. The term is used because potable water comes from an "open" source, such as a well or groundwater piping. ICS, direct thermosyphon and direct forced circulation systems are all open-loop.

**Closed-loop** is a system that circulates heat-transfer fluid (HTF) through a closed loop through the collectors and piping. Indirect thermosyphon, drainback, and antifreeze systems are all closed loop, using heat exchangers and HTF to transfer the solar energy from the collector loop fluid to potable water in a storage tank.

The SRCC denotes four main classifications within the open-loop and closed-loop types:

**Integral collector storage (ICS)** systems, or "batch" water heaters, combine the collector and the storage tank into one—the sun shines into the collector and strikes the storage tank directly, heating the water. ICS systems use a single large tank or a number of small (usually 4-inch-diameter) tanks in series, known as progressive-tube ICS.

**Thermosyphon** systems have a separate storage tank, located higher than the collector. Water is warmed in the collector and rises naturally to the storage tank where it is kept until needed. The tank must be above the collector for a thermosyphon to work correctly. Most thermosyphon systems are open-loop but some have a tank-integrated heat exchanger and are closed-loop indirect systems.

**Forced circulation** or "active systems" are those that use a pump to circulate the water or other fluid from the collector, where it is heated by the sun, to the storage tank, where it is kept until you need it. Forced circulation systems can be "direct" (commonly known as open-loop) and "indirect" or closed-loop (drainback and antifreeze).

The "self-pumped systems" category has no systems certified at this time.



## Batch Water Heaters

Batch water heaters have been heating water in the lower tier of states for more than a century. Take a cylindrical tank, paint it black, put it in an insulated box with glass on the top and you have a batch water heater.

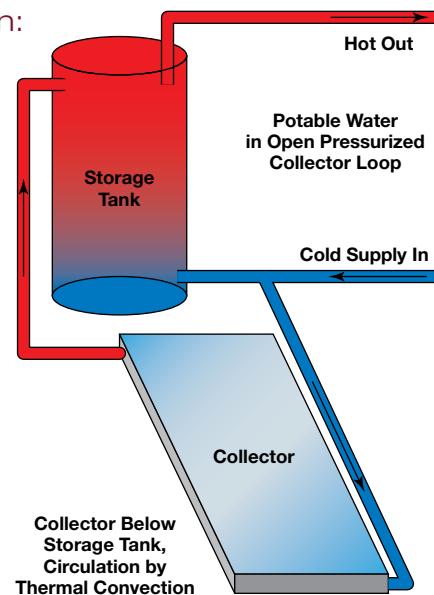
To provide some insulation on the glass side of the collector, most manufactured batch water heaters use double glazing. Operation is simple—sunlight shines through the glass, hits the black tank, and heats it and the water it contains.

ICS systems are considered “passive” heaters since they don’t require any electro-mechanical devices, such as pumps, to operate. Batch water heaters have high overnight winter heat loss because only the glass protects it from cold nighttime temperatures, though some hands-on owners place insulation over the glass at night. ICS units are typically only installed for year-round use in warmer climates like Hawaii, or states that border Mexico or the Gulf of Mexico.

## Thermosyphon

Thermosyphon systems are also considered passive systems, since they don’t require a pump or control. These systems can have either integrated or separate collectors and tanks, which can be more effective in retaining heat overnight, since the tank can be well-insulated. However, thermosyphon systems are usually more susceptible to freezing than batch water heaters because of the small riser tubes in the collector.

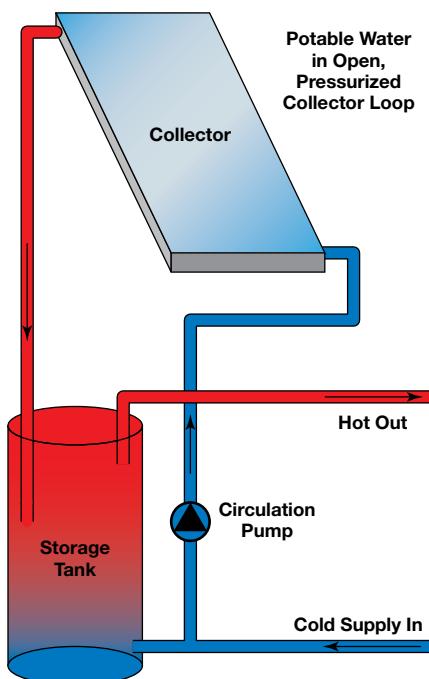
## Thermosyphon: Open-Loop



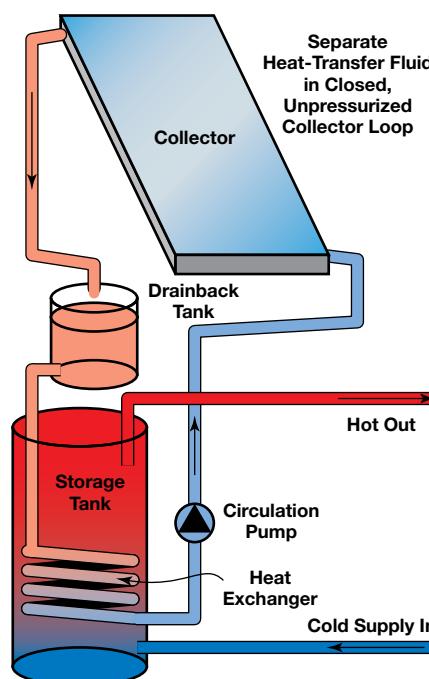
## Direct Forced-Circulation

Direct forced-circulation systems (DFC) (aka open loops) are very popular in locations where it never freezes, like Hawaii. The systems heat potable water directly, circulating it through the collector(s). The main components of a DFC system are a collector, tank, and pump; plus a control to energize the pump when there is enough sunshine to add heat to the water in the tank.

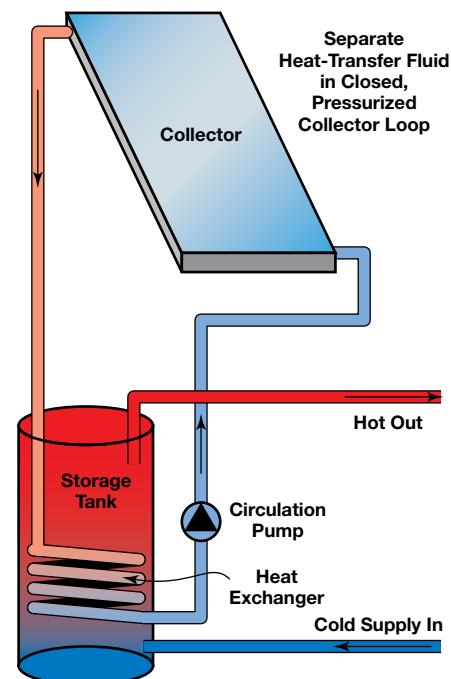
## Direct Forced-Circulation: Open-Loop



## Indirect Forced-Circulation: Closed-Loop, Drainback



## Indirect Forced-Circulation: Closed-Loop, Antifreeze



## The Components

### Collectors

The role of a thermal collector is simple—absorb sunlight, transfer heat, and do it reliably for decades. But collectors must absorb lots of heat, while minimizing solar loss from reflection and heat loss to the surrounding environment. Two main SHW collector types—flat-plate and evacuated-tube (ET)—are available to the residential market.

**Flat-plate collectors** are time-tested, reliable, and currently dominate the market. They have an absorber plate—a sheet of copper, painted or coated black—which is bonded to pipes (risers) that contain the heat-transfer fluid. The risers and copper are enclosed in an insulated metal frame, and topped with a sheet of glass (glazing) to protect the absorber plate and create an insulating air space. High-temperature rigid-foam insulation, low-iron tempered glass, and aluminum frames are most commonly used, and different absorber plate coatings are available, ranging from black paint to proprietary selective-surface coatings that maximize heat absorption and retention.

Flat-plate collectors usually range in size from 24 square feet (3 x 8 ft.) to 48 square feet (4 x 12 ft.) or more, and can weigh more than 150 pounds each. They hold a small volume of circulating HTF—typically less than 3 gallons, even in large collectors.

**Evacuated-tube collectors** are a more recent technology, introduced in the late 1970s. Several types are available, with the common element being a glass tube surrounding an absorber plate. Because the space inside the tube is a vacuum, which is a far superior insulator than air, these collectors have much better heat retention than the glazing/air space design of flat-plate collectors.

**Evacuated-tube collectors are touted as having better performance in overcast weather, but at additional complexity and cost.**



Courtesy Stephen Elton

**Flat-plate collectors**  
are a proven and simple  
technology for reliably making  
hot water.

### Indirect Forced-Circulation

Indirect forced-circulation systems (IFC) use a separate HTF that circulates and is heated in the collector. A heat exchanger transfers the heat from the HTF to the potable water in the storage tank. IFC systems all have one or two pumps, depending on the heat exchanger type. A system with an integral storage tank exchanger only needs one pump; an external heat exchange design needs two pumps. The two IFC systems—drainback and antifreeze—are the only truly freeze-protected systems. Both are closed-loop systems.

**Drainback** systems include a drainback tank, with or without an integral heat exchanger, plus one or two pumps, and a control for the pumps.

**Antifreeze** systems are the most complex and installation-intensive of all the SHW systems. These systems need an expansion tank, heat exchanger (internal storage tank or external), pump(s), a control, a temperature gauge, and pressure relief.

Most use borosilicate glass to maximize solar transmission to the absorber plate, and have similar absorber coatings to flat-plate collectors. Frames and manifolds for paralleling multiple tubes are available that can hold four to 20 tubes or more. As with flat-plate collectors, multiple banks can be plumbed together to increase system capacity. While overall weights and dimensions are similar between the two types, evacuated tubes usually have an advantage in that individual tubes can be carried to the location and then assembled on the roof, rather than lifting an entire collector.

## Freeze Tolerance

Protecting a solar collector from freeze damage increases the complexity and cost of most SHW systems. Virtually all SHW systems incorporate copper tubing in the collectors and/or piping systems. Water-filled pipes will burst from a hard freeze, since water expands as it freezes. Burst piping is difficult to predict, as many factors influence the conditions for freezing. Outside temperature and the length of time the temperature remains low are two important factors. Others are the tubing diameter and effectiveness of pipe or collector insulation.

The least freeze-tolerant systems are direct forced-circulation and direct thermosyphon systems. The relatively small (usually 1/2-inch or less) riser tubes in thermosyphon system collectors make these systems susceptible to freeze-burst damage at about 20°F ambient temperature. Any system with an integrated tank outside the heated space (ICS and thermosyphon) will have 3/4-inch potable water lines to and from the tank. Even if these lines are well-insulated, they are still prone to freezing between 0°F and 10°F ambient. Progressive-tube ICS systems are less tolerant and will freeze at higher temperatures (about 10°F to 20°F ambient) due to uninsulated 3/4-inch connection tubes inside the collectors.

A drainback system's freeze protection relies on the water in the collector loop draining back to the reservoir, leaving the collectors and piping filled with air. The collectors and all piping *must* be sloped so they will drain when the pump is de-energized. A path for air to rise from the drainback tank to the top of the collector must be included in the system.

For their freeze protection, antifreeze systems use the same concept used in cars: a 50/50 solution of antifreeze and water. SHW systems use nontoxic propylene glycol instead of the highly toxic ethylene glycol used in most automobiles.

### Freeze Tolerance by System Type

System Type	Freeze Temperature	
	Fahrenheit	Celsius
ICS batch heaters	10° to 20°	-12° to -7°
Direct forced circulation	20° to 40°	-7° to 4°
Drainback	-50°	-46°
Antifreeze	-60°	-51

These are approximate tolerances, check with the manufacturer for their recommendations on any specific system.

Collector mounts. Almost all collector manufacturers make the racks for their collectors. The mounting systems fit into the aluminum extrusions of the collector and typically will only fit that collector model. The mounting systems are usually aluminum or stainless steel. Many manufacturers can provide engineering reports for the wind-loading capability of their racks.

## Tanks

**Storage tanks** range from 40 to 120 gallons for residential systems. Electric water heaters can easily be adapted to serve as solar storage tanks. Specialty tanks come with or without integrated heat exchangers. Most tanks are glass-lined, but can be stainless steel or lined with high-temperature polybutylene plastic.

**Drainback (DB) tanks** or reservoirs for residential systems usually have a capacity of 8 to 20 gallons. Large DB tanks serve as both a drainback reservoir and storage for the system. The DB tank holds the collector loop water after it has drained from the collector and piping. DB tanks can simply be a small tank or can contain an internal heat exchanger. A DB tank should hold at least twice the volume of the system (piping, collector, and exchanger).



Some storage tanks have an integrated heat exchanger, as this cutaway shows, increasing efficiency and simplifying system plumbing.

Courtesy Bradford White



**Above:** A small electric water heater is used as a drainback tank, allowing heat-transfer fluid to drain from the collector when the system is not operating.

**Right:** A circulation pump in a drainback system has to be able to overcome the head from the tank to the collector.



**Right:** In a pressurized closed-loop system, one PV module can control a small DC pump.



**Expansion tanks.** Liquids physically expand when they get hot, and closed-loop systems need some way to absorb this expansion. In drainback systems, the DB tank serves this function. In antifreeze systems, expansion tanks are used. They are usually very small—2 to 4 gallons—and are sized depending on system volume and maximum system temperature.

**Backup water heater.** Many solar storage tanks have an electric element in the top of the tank, which serves as a backup source to heat the water when the SHW system doesn't produce enough hot water. Single-tank systems have less heat loss and take up less room than double-tank systems.

Two-tank systems use a solar storage tank and a backup gas or electric water heater, which keeps water hot under all conditions. This backup heater can also be a tankless or instantaneous water heater. Double-tank systems add to the overall system storage capability. However, since the storage tank doesn't have any conventional heating elements, conventional energy cannot preheat the water as it can in a single-tank system.

## Pumps

Pumps are used in forced-circulation systems to move the collector-loop fluid through the collector to the tank or heat exchanger. When an external heat exchanger is used in an indirect system, a pump is also required on the potable or DHW loop. When a pump is used to circulate potable water (open or DHW loops), it must be constructed of bronze or stainless steel because of the corrosive effects of the dissolved oxygen in potable water.

Drainback systems need a high-head pump large enough to push all the air out of the system on system startup and overcome the height of the collector. Antifreeze systems can use smaller pumps, since there is no air in the piping to overcome and the piping and collectors remain filled with the antifreeze. Because a smaller pump is needed, antifreeze systems more readily use PV-powered DC pumps. The pump industry has a very limited selection of high-head DC pumps suitable for drainback systems.

## Controls

Forced-circulation systems must have a controller to energize the pump. Since the water temperature in the tank will increase by 60°F or more on a sunny day, a differential control will maximize the system's efficiency. The control has a sensor



**A differential pump controller uses thermal sensors to determine when the collector temperature is high enough to add heat to the SHW tank.**

to monitor collector temperature and another to monitor tank temperature. The control turns on the pump when the collector is a few degrees warmer than the tank and shuts the pump off when the collector temperature drops below being able to add heat to the tank water. Many controls have digital displays, multiple differentials for multiple outputs, high-limit controls for storage tanks, and vacation modes to help avoid system overheating when a home is unoccupied.

## Heat Exchangers

Heat exchangers are a part of all indirect systems since the nonpotable collector loop fluid cannot mix with the potable water used at the tap. Exchangers are often built into storage tanks, simplifying the system by using only one pump and less plumbing. Tanks with built-in heat exchangers are much more expensive than no-frills storage tanks, which can be as simple as an electric water heater with unused electric elements.

However, no-frills tanks require an external heat exchanger and an extra DHW pump to circulate potable water from the storage tank to the exchanger. Drainback systems that have a DB tank with an integral heat exchanger also require two pumps, since the heat exchanger is not part of the storage tank.

## Valves and gauges

**Check valves** are required to prevent reverse circulation (thermosyphon) of the collector loop fluid at night. This can cause heat loss and frozen heat exchangers in antifreeze systems. Drainback systems cannot have a check valve, which would prevent the system from draining.

**Temperature & pressure relief valves** are required on all water heaters and storage tanks. These safety valves are usually set to "blow off" or activate on a condition of exceeding 210°F or 125 pounds per square inch (PSI).

A pressure relief valve is used on collector loops and is activated by system pressure only, for antifreeze systems blowing off at 50 to 75 PSI. Common causes of pressure relief activation are power outages and pump and control failures.

**Temperature and pressure-relief valves** are mandatory safety features.



**Antiscald valves** are important, since high system temperatures are possible.



**Temperature gauges** can help determine the state of a system at a glance.



Shawn Schrainer (4)

**Optional flow meters** show the flow rate of heat-transfer fluid through the collector loop. When placed at the top of the DB tank, they can also serve as a sight gauge to monitor liquid level in the tank.



**Isolation (bypass) valves** allow the solar part of the system to be isolated from the conventional plumbing system for maintenance.

**Mixing & antiscald valves.** SHW systems don't have thermostats like conventional water heaters and the storage tank can reach very high temperatures. Mixing, tempering, and antiscald valves all limit water temperature in the tank by mixing in a little cold water when water temps are too high. Antiscald valves have closer tolerances than mixing and tempering valves, and usually cost about twice as much. But if a system specifies an antiscald valve, a mixing valve is not an equal substitution.

**Pressure gauge.** An external charge pump is used on antifreeze systems to raise the system pressure to about 15 PSI upon filling.



Courtesy Taco

**Pump stations combine many system components into a single, easier-to-install package.**

The pressure gives the antifreeze solution a higher boiling point (about 250°F) to help limit pressure relief activation. The pressure gauge is the first place to check for problems with antifreeze systems—a reading of 0 PSI indicates that the system has a leak or the pressure relief has blown off.

## Pump Stations

Pump stations are component assemblies for antifreeze systems, containing the system pump, plus required drain, fill, check,

and pressure valves. Often, they will include the expansion tank and heat exchanger. Since pump stations all have check valves, they should not be considered for drainback systems.

Although SHW systems can be complex, with several components, there's no rocket science here, either.

## Access

Contributing editor Chuck Marken ([chuck.marken@homepower.com](mailto:chuck.marken@homepower.com)) is a New Mexico licensed plumber, electrician, and HVAC contractor. He has been installing and servicing solar thermal systems since 1979. Chuck is a part-time instructor for Solar Energy International and the North Carolina Solar Center and works under contract with Sandia National Laboratories supporting the DOE-sponsored Solar Instructor Training Network.

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### Further Reading:

- “Solar Collectors: Behind the Glass,” by Chuck Marken, *HP133*
- “Solar Water Heating Buyer’s Guide,” by Chuck Marken, *HP125*
- “Solar Hot Water Storage: Residential Tanks with Integrated Heat Exchangers,” by Brian Mehalic, *HP131*
- “SDHW Installation Basics, Part 2: Closed Loop Antifreeze Systems,” by Chuck Marken and Ken Olson, *HP95*
- “SDHW Installation Basics, Part 3: Drainback Systems,” by Chuck Marken and Ken Olson, *HP97*
- “Solar Hot Water Pump Stations,” by Brian Mehalic, *HP134*



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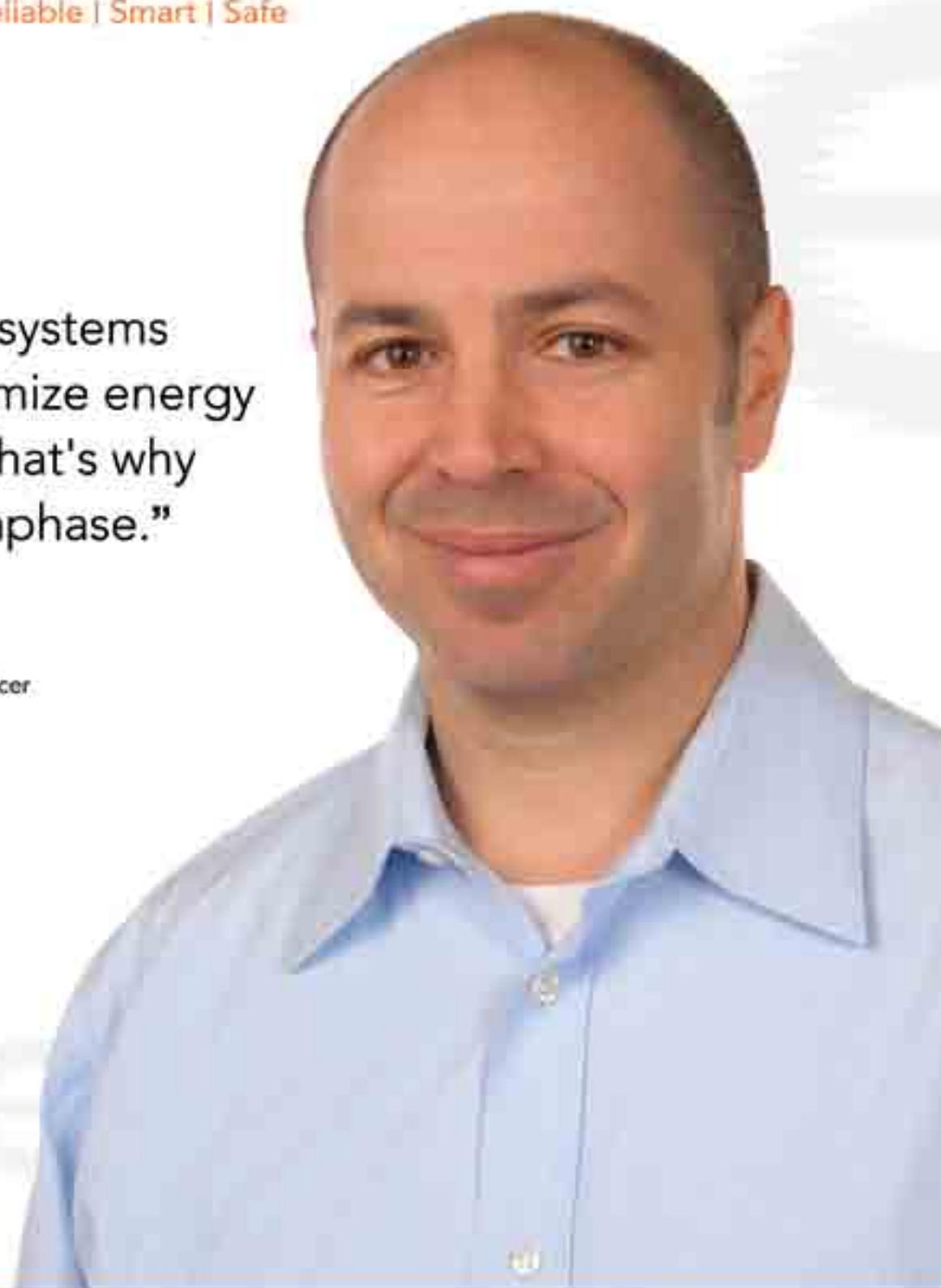
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# High Efficiency Appliances

## THE BEST OF THE BEST

Go beyond Energy Star to get the highest-efficiency appliances. Here's our guide to choosing models for your home that save energy and shave your utility bills.

by Karin Matchett

The evolution of household appliances spanned the 20th century, a period of time when the United States saw an abundance of new energy sources. Electric-powered household appliances proliferated. Refrigerators were common in urban homes by the 1930s. By the 1940s, a majority of American households had electric clothes washers, which co-existed with growing numbers of other consumer appliances that hummed, stirred, blinked and glowed in American homes.

Consumption of electricity burgeoned. Between 1950 and today, home electricity use increased 20-fold. In a world with no apparent energy constraints, appliance size and features steadily grew and multiplied. But that's changed: Faced with a dwindling supply of fossil fuels and unpredictable electricity rates, we're getting smarter about household energy use.

The Department of Energy and the Environmental Protection Agency's Energy Star program has been one of the leaders in establishing higher standards of energy efficiency. Other groups have joined the movement, including the Consortium for Energy Efficiency, a nonprofit energy-efficiency advocacy group, making choosing new, energy-smart appliances easier than ever.

### Decisions

The models listed here are among the most energy-efficient models widely available. If you think that you need features that these models don't have, consult directly with the organizations that compile the data and query it with your needs in mind. The Consortium for Energy Efficiency (CEE) takes Energy Star data and pushes energy efficiency advocacy a few steps further, focusing on the most efficient end of the Energy Star spectrum. CEE's Super Efficient Home Appliances Initiative ranks appliances in two or three tiers, and encourages manufacturers toward even more rigorous efficiency. The CEE updates its appliance lists every month on its website—an excellent place for up-to-date listings of the most energy-efficient appliances.

When you need to replace an appliance, doing your homework will pay off. Efficiency standards will take a big jump in the next few years—a coalition of appliance manufacturers and energy efficiency advocates recently reached an agreement on new, more stringent efficiency requirements, and their

recommendations were adopted by the U.S. Department of Energy in September 2010. Those new federal efficiency standards will go into effect in late 2014 and early 2015.

### Now?

When is it prudent to replace an inefficient but still functioning machine? Check out Energy Star's history of standards revisions—if your appliance is old and standards have raised the bar well beyond what it can achieve, it may be beneficial

**The introduction of home appliances accounted for part of the surge in residential electricity use over the past century.**



Courtesy Whirlpool

## Beyond Energy Star

Consumers' most visible tool for locating efficient appliances is the Department of Energy and the Environmental Protection Agency's Energy Star label. Energy Star's objectives are to diminish air pollution (including greenhouse gas) and to offer consumers a simple way to select energy-efficient appliances to lower electricity consumption.

Energy Star is a useful guide, but it's not perfect and it's not as ambitious as some would wish. The Energy Star label is for appliances that "deliver the features and performance demanded by consumers." That means that if consumers are "demanding" an energy-intensive feature, even if it doesn't perform a critical function (like a refrigerator's in-door icemaker), an Energy Star label will be applied to a percentage of models with that feature. The label notes the relative efficiency of products within a subcategory (e.g., side-by-side refrigerators), not within the broad category (refrigerators). So, if you're after the best of the best, you need to first determine which subcategory offers the most efficient model before you put any weight on an Energy Star label.

The Energy Star label is used only on models for which consumers recoup any premium on the price tag within a "reasonable period of time." This means that an out-of-this-world efficient appliance that doesn't run much of the time (therefore doesn't add much to your utility bill) and costs 30% more than an energy-hog model would not get the label. Finally, Energy Star ratings are based on testing done by the manufacturer. In addition to the problems inherent in self-reporting, this testing is not always done under typical operating conditions, leading to misleading rankings in some cases.

The selections here are based, by necessity, on Energy Star data, but also rely on the Consortium for Energy Efficiency's ranking, which divides Energy Star-qualified appliances into two or three tiers. Not all of these models are a cinch to find (like some of the window air-conditioners listed), so we've included the hard-to-find models along with some easier-to-find ones, even if they're slightly less energy efficient.

Models and availability constantly change, but you can use this article as a sample roadmap for your future appliance purchases.

(financially and environmentally) to buy a new one. If your old machine is of a style that inherently guzzles electricity, you have yet more reason to consider replacing it now rather than waiting.

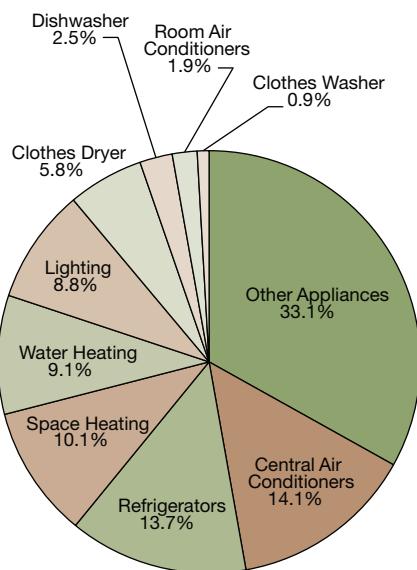
### What's in It For Me?

The most efficient models are sometimes not the cheapest ones up-front. While payback is usually defined in terms of money saved, it can also mean lightening the load on the

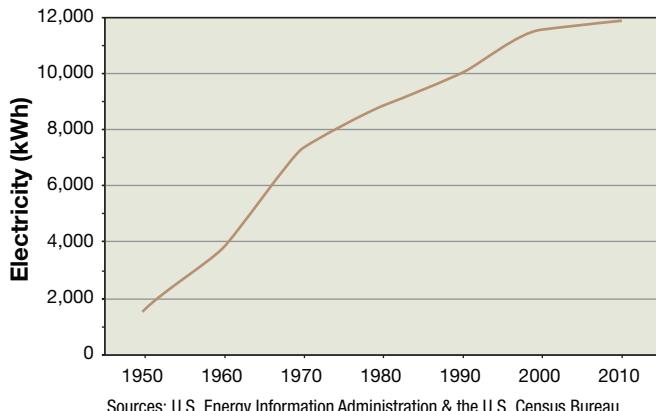
electrical grid, consuming less of our increasingly limited resources and emitting fewer greenhouse gases.

By replacing an appliance, you'll spend less money month to month. In many cases, the savings over time is greater than the purchase cost. In other cases, the higher price of the efficient model may never be recouped within the life of the appliance, particularly if your electricity is cheap. In this case, you won't see a payback in terms of actual dollars, yet you'll have attained other non-economic goals from the day you plugged it in.

## Residential Consumption of Electricity by End Use



## Yearly U.S. Household Electricity Use (Retail Sales)





Courtesy Fisher & Paykel

**Multidrawer dishwashers aren't necessarily the most efficient overall, but they can save energy by allowing efficient-sized loads.**

## Dishwashers

What's the most energy-efficient way to clean your dishes: hand-washing or using a dishwasher? While hand-washing may seem more energy efficient, it actually isn't unless you're very frugal with the water (or have solar-heated water). Using a dishwasher can be considerably more energy efficient *if* you choose your appliance intelligently. (To use the least amount of electricity, run the dishwasher only when it's full and let the dishes air-dry.)

The most energy-consumptive part of dishwasher action is not the operation of the motor, but rather the production of heat. This includes heating the water (by the home's water heater, as well as the dishwasher's own booster heater) and the heat generated to dry the dishes. The less hot water you use and the less you use the dishwasher's drying function, the smaller the model you can buy and the more energy you'll save. Look for models that give you options, such as soil sensors and wash cycle selection.

## Energy- & Water-Efficient Dishwashers

Model	Gal. / Cycle	kWh / Yr.
Bosch SHV58E13UC & SHX58E15UC	1.56	259
Thermador DWHD650G & DWHD651GFP	1.56	260
Bosch SHE68E05UC, SHE68E15UC, SHV68E13UC, SHX68E05UC, & SHX68E15UC	1.56	180
Gaggenau DF260 & DF261	1.56	180
Bosch SGE63E0UC	1.56	234
Bosch SHE68P0 series, SHV68P03UC & SHX68P05UC	2.21	234
Kenmore 1332*	2.70	174
KitchenAid KUDD03ST*	2.70	174
DCS DD124*	2.87	160
Fisher & Paykel DD24S*	2.87	160
Asko D5893XXL	3.80	187

\*Compact models

Dishwasher efficiency standards are based on annual kWh consumption, gallons of water used per cycle, and Energy Factor, EF, which reflects the number of cycles performed per kWh. The most energy-efficient models are in CEE's Tier 2, in which standard-sized models (those that can handle eight or more place settings) can use no more than 295 kWh per year and 4.25 gallons per cycle, and must have an EF of at least 0.75. For compact models, the limits are 222 kWh per year, 3.50 gallons per cycle, and an EF of at least 1.00.

You'll find models that use relatively little electricity but more water, and vice versa. The choice will need to be made based on the source of your electricity and the fuel you use for water heating.

The compact dishwashers don't tend to outperform the standard-sized machines in water use, but they use less electricity. They take up less room and a full load is quicker to come by.

## Window Air Conditioners

Window air conditioners arrived on the scene somewhat later than electric refrigerators and clothes washers, but in hot and humid parts of the country, their usage rivals that of home heating in Minnesota. Window air conditioners are ranked according to their Energy Efficiency Ratio (EER). Higher-efficiency models have more efficient compressors, pumps and fans, and more effective heat-transfer surfaces. Interestingly enough, these don't necessarily carry a higher price tag compared to less efficient models. Before you buy, think well about whether you even need a window air conditioner (versus the smart use of fans and window coverings, which may suffice in many climates). But if you need one, here are some of the best.

Different sizes and types of air conditioners have different federal standards for minimum EER, and the current Energy Star standard requires a model to be at least 10% more efficient than the federal standard. The playing field is very crowded around an EER of 10.8, exactly 10% over federal standards. A few models pull ahead in the 11 to 12 EER range, and a selection of models of different capacities is included in the table.

The diversity of sizes and designs is particularly great for air conditioners, and before your next purchase you will want to consult the Energy Star website directly and peruse its long list of rankings.

## Rebates & Tax Incentives

Federal, state, and utility incentives for energy efficiency can be found at [www.dsireusa.org](http://www.dsireusa.org).

### State

The American Recovery and Reinvestment Act of 2009 provides funds to the states for appliance rebate programs. See [www.energysavers.gov](http://www.energysavers.gov).

### Federal

For more details on current federal tax credits, see [www.energysavers.gov](http://www.energysavers.gov).

### Utilities

Many utilities offer rebates for energy-efficient appliances. See the details for your state at [www.dsireusa.org](http://www.dsireusa.org).

Energy Star has a rebate-locator tool, searchable by zip code, which includes programs offered by its partners (which include some, but not all, utilities and appliance manufacturers). See [www.energystar.gov](http://www.energystar.gov)

Window air conditioners are good for cooling individual, small spaces.



## Window Air Conditioners

Model	Btu / Hr.	EER
Frigidaire FAA055T7A	5,200	11.0
Carrier ACA051T	5,400	11.2
Kenmore 75052	5,700	11.2
Friedrich XQ06M10	6,000	12.0
Haier ESAD4066	6,000	12.0
Friedrich YS09L10	9,200	12.0
Friedrich SS10M10	9,500	12.0

Courtesy Friedrich

## Washing Machines

Washing machines, like dishwashers, need to be considered based on the energy to run the appliance itself, the heated water used, and the work left after the washing is complete—by the dryer. Of course, you can decrease your energy use by washing in cold water and drying with a clothesline. Then use a wisely chosen machine, and your laundry energy consumption will be the envy of your neighbors.

Features to consider include size (think carefully about what you really need), horizontal or vertical axis, whether or not the model has a water-level sensor and an option for a fast final spin. Front-loading (horizontal-axis) machines are the most energy efficient because they use less water and less electricity, and they wring out more water after the wash—and they're easier on clothes.

Clothes washers are ranked according to their modified energy factor (MEF), the number of cubic feet of laundry that can be washed and dried using 1 kWh of electricity, and water factor (WF), the number of gallons required to wash 1 cubic foot of laundry. Conveniently, the models with the highest MEF also have a low WF. Energy Star standards require a MEF of at least 1.8 and a WF of 7.5 or less, but there are many machines that go well beyond this.

## Clothes Washers

Model	MEF	WF
Whirlpool WFW97HEX	3.35	2.65
Maytag MHW7000X	3.30	2.70
Whirlpool WFW95HEX	3.30	2.71
Electrolux EWFLS70J	3.29	2.80
Maytag MHW6000X	3.30	2.70



Courtesy Whirlpool

Washing machines can save energy in several ways: electricity used, hot water used, and water extracted (saving energy costs during drying).

## Efficient Ovens & Cooktops

For ovens and cooktops, energy savings are less dependent on the model and more tied to the choices made by the cook about what type of appliance to own, and which appliance and cookware to choose for a particular task.

The greatest energy leak in the kitchen is your oven—only a fraction of the energy it consumes cooks the food. If you must turn it on, then bake several dishes at once, avoid preheating, and turn off the oven before the baking time is complete. When possible, opt instead to use the stove-top, a high-quality toaster oven, an electric cooker, or a microwave—depending on the situation.

Self-cleaning ovens are better insulated and thus more efficient, as are convection ovens, which cook food more quickly and at lower temperatures. On top of the stove, induction cooktops offer the greatest energy efficiency (though they are expensive). Induction cook-tops generate a magnetic field under the stove's glass surface, creating heat in an iron or steel pot. The heat is confined to the cookware and food, leaving a cooler kitchen and consuming less energy.

## Doing Things Differently

Even if you don't (yet) have the best of the best appliances, there are many things you can do to cut down on kitchen energy use.

**Don't keep the pot at a rolling boil.** A rolling boil is no hotter than a simmer. Turn down the heat.

**When you make hard-boiled eggs, forget the boil entirely.** Well, almost. They don't need a full boil to cook. Bring the pot to a boil, turn off the heat, cover with a lid and let the eggs sit for 12 minutes. This works well for pasta, too.

**Use a solar oven.** On sunny days, a well-insulated solar oven can reach temperatures above 200°F. While solar ovens aren't a good choice for a soufflé, they excel at baking bread or squash, and cooking rice, stews, and soups. Put it on in the morning, and dinner's ready when you get home—and the kitchen's still cool. You can build your own (a great project for kids) or buy a commercially made unit (see [www.solarovens.org](http://www.solarovens.org)).

**Fill the empty space in your refrigerator with jugs of ice.** Winter temperatures can freeze or cool jugs of water that you then put in your fridge. With airspace taken up by cold water, your fridge will run less.

## Refrigerators

Your refrigerator cycles on and off, all day and all night. So does your neighbor's refrigerator. And his uncle's refrigerator. All told, refrigerators account for about 15% of U.S. residential electricity use. In the past couple of decades, refrigerators have had tremendous efficiency gains. Since 1990, energy use by models with a top-mounted freezer has been cut in half, and new standards set for 2014 will take an additional bite out of refrigerators' electricity consumption.

The energy use of different styles of refrigerator-freezers varies. The side-by-side configuration uses more than a refrigerator with the freezer on top, with bottom-mounted freezers weighing in somewhere in between. Door-mounted ice and water dispensers increase energy use dramatically.

The models listed have capacities of about 18 cubic feet and some of the lowest electricity usage. All have top-mounted freezers and none has an in-door ice machine. Numerous models in this size range are rated at 335 kWh/year (versus the federal standard of 480 kWh/year). Most manufacturers make several models similar in efficiency to those listed here, as well as similarly efficient models of different sizes.

Before you buy a new refrigerator, take a close look at your needs; buy the smallest unit that you think is manageable. If you don't need a freezer at all, you can lower your energy use even more. And no matter what size or model you own, don't turn the thermostats any colder than necessary. Make sure the door seal is in good condition, and keep the fridge and freezer full (with water jugs, if not perishable food).

## Fridges

Model	Size (Cu. Ft.)	kWh / Yr.
Frigidaire LGUI1849L	18.20	335
GE GTH18	18.11	335
Hotpoint HTH18	18.11	335
Kenmore 970-43962	18.18	336



Courtesy GE

**Today's energy-efficient refrigerators are far better than models from even 10 years ago. Leave off the bells and whistles, like in-door ice service, for even better performance.**

## Count Your Watts

To compare your current appliance with those on the market, use a watt-meter to determine how much electricity is used by an appliance. A common, inexpensive model is the Kill-A-Watt EZ. It not only measures electricity use, but also allows you to enter your utility rate and estimate the cost of running the appliance over the course of a week, month, or year.

## Access

Karin Matchett ([wordcraft@karinmatchett.com](mailto:wordcraft@karinmatchett.com)) is a writer and editor working in the Midwest and on the road. She covers topics in renewable energy, energy efficiency, woodworking, gardening, science, and medicine, and is dedicated to finding ways to rehabbing old, urban houses.

### Resources:

American Council for an Energy-Efficient Economy • [www.aceee.org](http://www.aceee.org)

Energy Star • [www.energystar.gov](http://www.energystar.gov)

Consortium for Energy Efficiency • [www.cee1.org](http://www.cee1.org)



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# High Style,

# High Performance

*What does it take to build a high-performance home?  
Determination & attention!*

by Ian Woofenden

When it comes to building an energy-efficient home, keeping everyone focused on the goal is key. Otherwise, conventional designers and contractors may do what they've always done—build conventionally, and the result will be conventional (mediocre) building performance. But one Northwest couple kept their eyes on the prize, and reaped the rewards.

When Jim and Sue Nichol started planning their new home on Guemes Island, Washington, in August 2008, they were determined to have a fine custom and green home. They wanted to live comfortably as they moved toward retirement, and they wanted to reduce their environmental footprint. A goal was to keep maintenance and utility costs down while enjoying their stunning view. They were stimulated by the challenge of designing their home, and helped by a crew of forward-thinking consultants and contractors.

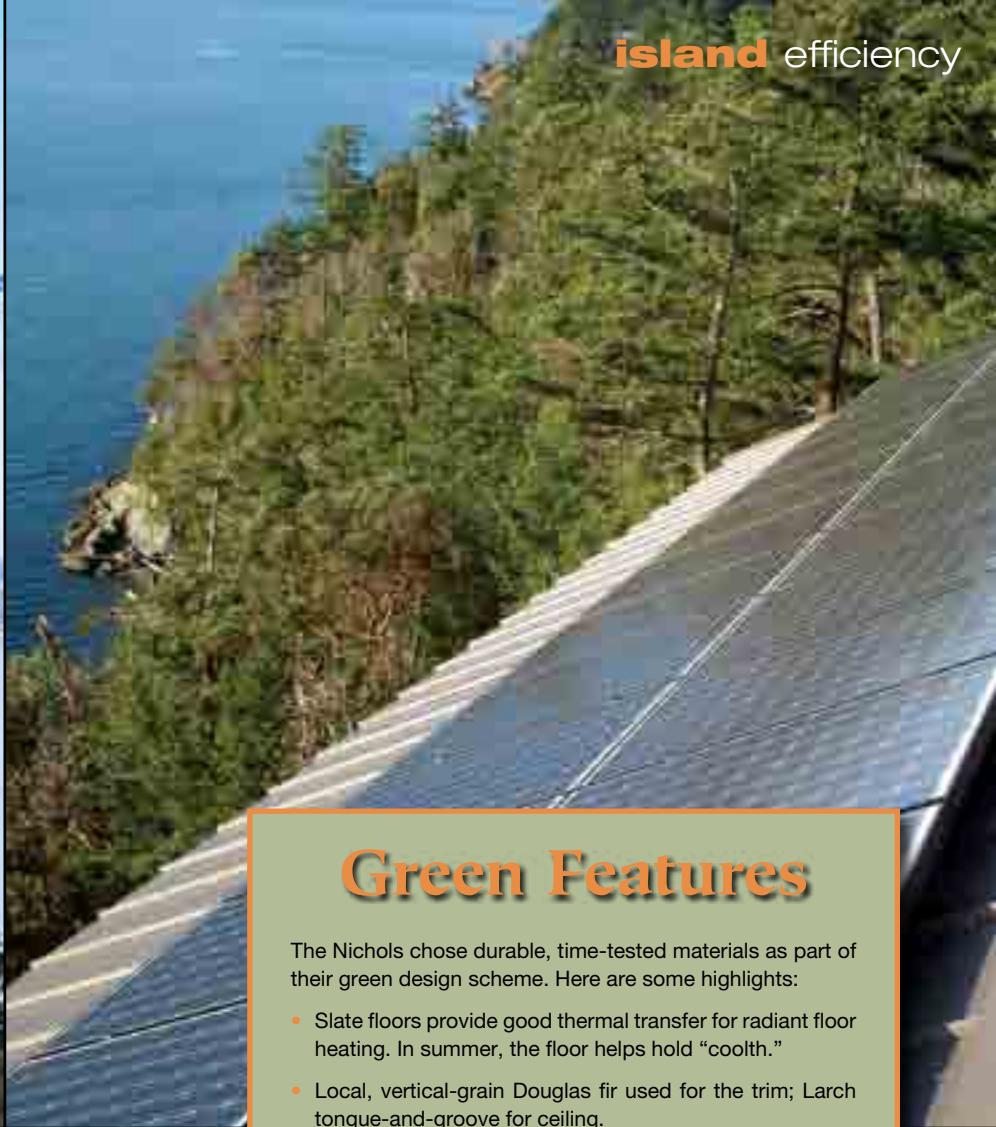
Their building designer, Art Peterson of Cedar Tree Associates Architects, has been involved in sustainable design for many years, focusing on smaller homes, passive solar design, and green materials. I was a minor part of the design team as well, steering the project toward energy efficiency and renewable energy. Jim and Sue took an active role in the design process, and this was a key factor in the success of the project. With a little direction, the Nichols worked on their goals—by doing research, finding appropriate contractors, and making sure they got what they wanted at each stage of the game.

Jim and Sue ended up with a luxuriously comfortable, high-performance home. In their first year of occupancy, they heated the 2,000-square-foot home for \$380 (\$1.04 per day), in a neighborhood where other homeowners are paying more than \$1,000 per year to heat similarly sized homes.



# ance

**Jim and Sue Nichol put energy-efficient design first for their Guemes Island, Washington, home. Then they implemented energy-saving systems and appliances, and, finally, renewable energy systems, like this 5.7 kW PV system.**



## Green Features

The Nichols chose durable, time-tested materials as part of their green design scheme. Here are some highlights:

- Slate floors provide good thermal transfer for radiant floor heating. In summer, the floor helps hold “coolth.”
- Local, vertical-grain Douglas fir used for the trim; Larch tongue-and-groove for ceiling.
- Solar tubes (solar skylights) provide natural daylighting to the master bathroom, bedroom, and kitchen.
- Toto Aquia Dual Max toilets reduce water use with two flushing levels—0.9 gallons for liquids; 1.6 gallons for solids.
- Low-flow showerheads.
- A TRD1000 septic treatment system treats the sewage with ultraviolet light and aeration, producing a potable outflow—this was necessary since the home is built on solid bedrock with no place for a septic leach field.
- HardiePlank cement-board siding, which has an expected lifespan of more than 50 years, was used as exterior cladding on the first floor of the house. The siding on the upper floor of the house, which will receive less wear and tear, is repainted cedar shingles.
- The home’s roofing is standing-seam metal, with an expected life of more than 30 years. It provides a collection surface for rainwater to use for plants, car washing, etc. A 1,250-gallon underground storage tank catches rainwater, which can be pumped up to irrigate the living roof and other plants.
- A living roof over the garage—with a 60-mil EPDM liner covered with 6 inches of soil and planted with sod—provides the Nichols with lawn space.

### Addressing the Envelope

One of the most important factors in the building design was the choice of building envelope. Jim and Sue decided on structural insulated panels (SIPs)—polystyrene foam sandwiched between two pieces of oriented strand board. The polystyrene provides high insulation value (about R-4 per inch), while the OSB provides structure. Typically manufactured in 4-foot widths, SIPs help minimize thermal bridging through the building’s envelope compared to a conventionally constructed, 2-by-4 or 2-by-6 stud-framed home.

Different panel thicknesses are available to meet the design goals for a particular home. The Nichols chose 10-inch panels to provide R-39 for the walls and the cathedral ceiling. This is on the high end of recommendations for the area’s climate but maximized energy savings—what Jim and



Sue wanted. The thick SIPs also gave them deep windowsills, which they enjoy.

Over 10 days, two truckloads of SIPs that made up the walls and ceilings of the house and garage were installed. The pieces were lifted by a boom truck and tied together via lapping OSB edges and the 2-by-10 lumber pieces at the edges of the panels. Joints and corners were insulated with expanding spray foam, both during assembly and afterward, to complete the tight building envelope.

The Nichols chose Milgard double-pane, argon gas-filled aluminum windows, with low-E coatings. The exterior doors are insulated fiberglass. All windows and doors were installed with care and edges spray-foamed to minimize air infiltration.

### Innovative & Efficient Heating

With a tight and well-insulated building envelope in place, the next area of focus was a high-performance heating system. Though solar methods are great, the cloudy, wet winters in northwest Washington are not very conducive to solar space heating.

My suggestion was to marry an air-source heat pump with a hydronic radiant floor system. Jim connected with Handy's Heating in Mount Vernon, Washington, to install a York Affinity 8T series heat pump and an Aqua Products heat exchanger to move the heat from the heat pump into the hydronic system. While ground-source heat pumps get a lot of press, their air-source cousins are cheaper by a significant margin, and very appropriate in a temperate, maritime climate. We get only a few weeks of freezing weather per year, and the York unit is designed to perform well down to 20°F.

All heat pumps are actually renewable energy collection devices, since they don't make heat, but *move* heat from the air, ground or water. Think of them like your refrigerator, pumping heat out of the fridge box so it stays cold. Heat pumps transfer naturally occurring heat from the air outside your house into your house. One kilowatt-hour of electricity can pump anywhere from 2 to 5 kWh of natural heat.

This trumps traditional boiler or heater efficiency, since it translates to between 200% and 500% efficiency on their scale. The best modern conventional gas and electric heating plants have efficiencies in the mid-90% range.

Marrying an air-source heat pump to a hydronic radiant floor takes an efficient energy-collection system and couples it to an efficient heat-delivery system. Jim and Sue's two-story home has six zones of hydronic tubing in its floors, allowing them to heat only the spaces they need. Radiant floor system owners are almost universally pleased with the thermal comfort of their homes—with warm feet, air temperature needn't be as high as with conventional forced-air systems.

**Top:** An open kitchen with energy-efficient appliances.

**Middle:** Durable slate tiles are perfect for radiating the heat from the subfloor hydronic loops.

**Bottom:** The thick SIP walls make rooms cozy and comfortable.



**Structural insulated panels for the exterior walls and roof are not only efficient; they also come pre-cut so the house goes together quickly.**



**Made of expanded polystyrene and oriented strand board, SIPs are relatively easy to maneuver by hand.**

### Smart Energy Use

A sensible strategy for an energy-efficient home is to first build a tight envelope; then design and install an efficient heating (and/or cooling) system; and, third, focus on energy-efficient lighting and appliances. After these steps have been met, *then* generating some energy can be considered, evaluating the renewable resources available.

While Jim and Sue could have taken shortcuts by just writing a check for a big PV system to cover their electrical usage, they instead took a whole-house approach, starting with efficiency first, which results in lower consumption and a smaller RE system. The home was designed with an obstruction- and shade-free roof, facing as close to true south as possible while still preserving views from the house. The roof has a 38° pitch to optimize year-round solar electricity collection.

Since their home is far from the island's underwater electricity cable and critical services, the Nichols had already decided that they wanted generator backup—their neighborhood can experience multiday outages. They chose a 17 kW auto-start propane generator, which can run all of their loads—including the heat pump—during an electrical outage. The 250-gallon propane tank is large enough to provide six days of running time.

With a generator eliminating the need for battery backup, a batteryless solar-electric system was designed and installed by Whidbey Sun & Wind of Coupeville, Washington. The 5.7 kW

system uses a 6 kW Sunny Boy inverter and 30 Sanyo 190 W PV modules. The high energy-density Sanyo module line provided the maximum (at the time) output for the square footage available. Because the annual home load was unknown at the time of construction (indeed, until after the house had been lived in for a year), the Nichols chose to invest in a system that would give them significant generation and allow for expansion.

Using less-efficient modules could have given the same performance as the existing system, but would have used



**The steep coastal building site lacks yard space, so the Nichols got creative, establishing a living roof—and lawn—above the garage.**





## Fresh Air in a Tight Home

Building a tight home has many advantages, but at least one disadvantage—lack of fresh air. Tight, well-insulated homes need a mechanical solution for adequate fresh-air exchange. In the Nichols' home, a heat-recovery ventilator (HRV) was installed to avoid mildew and mold buildup and ensure good indoor air quality. The Venmar HEPA 4100 recaptures 80% of the heat in the air being expelled from the building, so that incoming air is preheated—not cold and drafty. The system includes a high-efficiency particulate air (HEPA) filter, removing particles as small as pollen from the air entering the house, something Jim appreciates because he has allergies.

the whole roof instead of only two-thirds of it. Leaving some roof space allows the Nichols to expand the system in the future by adding more modules.

In its first year, the system generated 6,500 kWh, which is about 50% of the building's usage. (Their total usage was about 6,000 kWh for heating and hot water, plus 5,811 for the motor home, lighting, computers, appliances, printers, etc.) Two dedicated kWh meters tracked the electricity usage for space and water heating. For the period of June 2009 through June 2010, the cost of space heating was \$1.04 a day; water-heating cost averaged \$1.49 a day. A solar water heater and/or on-demand water heater could have reduced that expense significantly, but the Nichols opted to focus on solar electricity, and have no plans to add a SHW system.

Incentives in Puget Sound Energy's service area include the 30% federal tax credit, a sales tax exemption, net metering, and production payments. Net metering means that Jim and Sue are credited (at the retail rate) for every kilowatt-hour their system "sells" back to the utility. Net-metering accounting in Washington zeroes on April 30, when the client pays for any shortfall or gives up any surplus. The total net-metering value of electricity on the Nichols' system for the first year was about \$650, which is credited on their bill. In Washington, the production incentive pays 15 cents per kWh to the Nichols, who will receive a check for about \$1,000 each year. (The rate is higher if Washington-made components are used.)

### Green Payback

Building "green" can be more expensive—Jim guesses that the PV system, coupled with speciality eco-friendly products, added about 30% to the home's construction costs. But he calculates that if they stay in the house 7 to 10 years, they will recoup the additional upfront expense. They also will have the security of long-term fixed costs for a significant portion of their heating and lighting expenses as the cost of energy keeps rising.

**Left: An air-to-water heat pump system is more than twice as efficient at heating as conventional space-heating systems.**

**Right: The PV system's 6 kW SMA America Sunny Boy inverter, AC disconnect, production meter and utility connection.**





Jim and Sue Nichol enjoy the view from their comfortable, energy-efficient home.

The Nichols have found a healthy balance between their lifestyle and their environmental goals. And they have used their financial success to promote a model of home design that combines comfort and beauty with environmental awareness. By keeping their focus on their goals, and by assembling a team of people willing to work toward those goals, they have a well-designed and relatively low-impact home they can feel proud of and enjoy in their retirement years.

#### Access

Home Power senior editor Ian Woofenden (ian.woofenden@homepower.com) enjoys helping people reach their energy goals based on their own motivations. He lives, works, and travels on planet Earth, including Washington's San Juan Islands.

#### Design & Build Team:

Cedar Tree Associates Architects • Architect

Premier Building Systems • [www.pbssips.com](http://www.pbssips.com) • SIP manufacturer

TC Legend Homes • [www.tclegendhomes.com](http://www.tclegendhomes.com) • SIP installer

Crater Lake Building Company • General contractor

Handy's Heating • [www.handysheating.com](http://www.handysheating.com) • HVAC contractor

Minaugh Excavation • Site prep and septic

Snowy Mountain Excavation • Living roof installation

Whidbey Sun & Wind • [www.whidbeysunwind.com](http://www.whidbeysunwind.com) • PV system

#### Components:

Sanyo • [www.sanyo.com](http://www.sanyo.com) • PV modules

SMA America • [www.sma-america.com](http://www.sma-america.com) • Inverter

Venmar • [www.venmar.ca](http://www.venmar.ca) • Heat-recovery ventilator

York UPG • [www.yorkupg.com](http://www.yorkupg.com) • Air-source heat pump



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3200W peak solar thermal output from 43 SF (4m<sup>2</sup>)

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ES-A-200-FA3	\$2.25/W	CS6P-225	\$2.05/W	SUN-20	\$2.50/W
ES-A-205-FA2	\$2.25/W	CS6P-230	\$2.05/W	SUN-25	\$2.50/W
ES-A-205-FA3	\$2.25/W	NB5olar		SUN-30	\$2.30/W
ES-A-210-FA2	\$2.25/W	Z30W	\$2.05/W	SUN-35	\$2.30/W
ES-A-210-FA3	\$2.25/W	Suntech		SUN-40	\$2.30/W
ES-A-215-FA2	\$2.25/W	STP260-24/Vd	\$2.05/W	SUN-45	\$2.30/W
ES-A-215-FA3	\$2.25/W	STP270-24/Vd	\$2.05/W	SUN-50	\$2.30/W
Pallets	\$2.15/W	DuPont		SUN-55	\$2.30/W
Containers	\$1.98/W	DA100-A2	\$1.40/W	SUN-60	\$2.00/W
Megawatt	\$1.85/W	DA90-A2	\$1.40/W	SUN-65	\$2.00/W
		DA95-A2	\$1.40/W	SUN-70	\$2.00/W



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# Choosing a Grid-Tied Inverter

by Ryan Mayfield

Very rarely are any two PV systems the same, and even ones that are similar present their own challenges and nuances. Before you move forward with an installation, you need to spend some time designing the system and evaluating your options, including component choices.

**A**fter modules, inverters are the most important PV system component to consider. The recent resurgence of microinverters and the release of DC-to-DC optimizers and other “distributed architecture” products have changed design choices—but they haven’t eliminated the need for careful, proper design (see “Distributed MPPT” in *HP137*). This article focuses on standard grid-tied string inverters and their design parameters. For a complete list of inverter design factors, see the “Buyer’s Guide” in *HP133*.

## Factors & Features

Breaking down the decision process into smaller parts makes the design process easier and less risky. Each decision can build on the previous, allowing you to grow the entire design logically.

Start with the specs provided by both module and inverter manufacturers. Make sure you are using the correct specifications for the products you'll be using—many companies make similar-looking models that have different electrical characteristics.

First, determine the PV array's location. The available area for the modules, shading issues, the need for using multiple roof orientations, and other physical limitations will dictate the overall PV array size. These site limitations will also play a role in determining what inverter is appropriate for your location (see "Solar Site Assessment" and "Optimizing a PV Array" in *HP130*).

## Power Ratings

Grid-tied inverters are most commonly rated by their continuous output (AC) power capability—the watts the inverter can output continuously. In the *National Electrical Code*

# Typical Grid-tied Inverter Spec Sheet Data

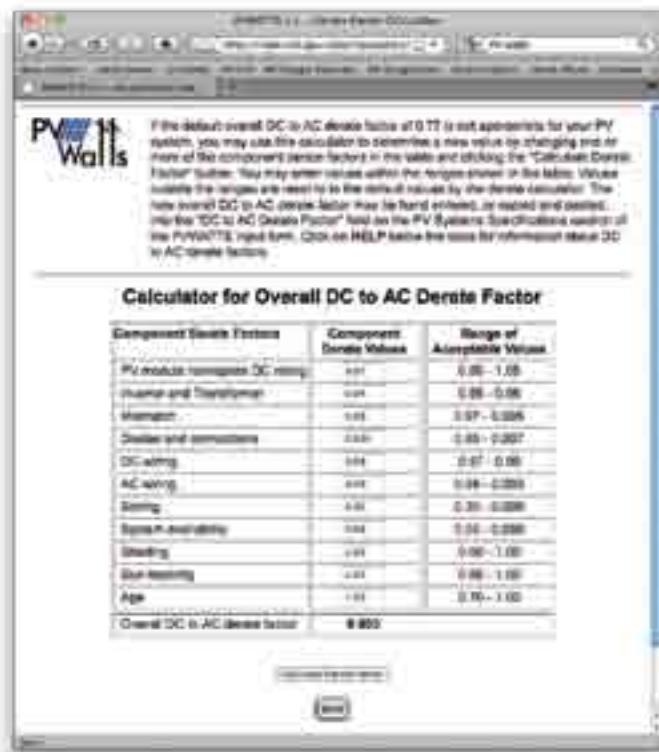
SB 5000US	
Recommended Maximum PV Power (Module STC)	6250 W
DC Maximum Voltage	600 V
Peak Power Tracking Voltage	250–480 V
DC Maximum Input Current	21 A
Number of Fused String Inputs	3 (inverter), 4 x 20 A (DC disconnect)
PV Start Voltage	300 V
AC Nominal Power	5000 W
AC Maximum Output Power	5000 W
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 21 A, 18 A
AC Nominal Voltage Range	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V
AC Frequency: nominal / range	60 Hz / 59.3 – 60.5 Hz
Power Factor (Nominal)	0.99
Peak Inverter Efficiency	96.8%
CEC Weighted Efficiency	95.5% @ 208 V 95.5% @ 240 V 95.5% @ 277 V
Dimensions: W x H x D in inches	18.4 x 24.1 x 9.5
Weight / Shipping Weight	141 lbs / 148 lbs
Ambient Temperature Range	-13 to 113 °F
Power consumption at night	0.1 W
Topology	Low frequency transformer, true sinewave



(NEC), a continuous load is defined as “a load where the maximum is expected to continue for 3 hours or more.” All circuits associated with grid-tied PV systems, on both the AC and DC sides of the inverter, are considered continuous.

This continuous power output rating dictates the PV array's maximum power value. Grid-tied inverters will limit their power output—if you design an array that supplies more power than the inverter's maximum, the inverter won't be able to process all the power. Instead, the inverter will waste any excess power as heat. As is the case with all electronics, generating unnecessary heat may reduce the inverter's life.

Online string-sizing calculators can take the guesswork out of matching a PV array to an inverter.



This screen shot from NREL's PVWatts program details some of the factors that reduce PV array output. Not shown here is power loss due to temperature, which PVWatts accounts for separately. While PV array DC output is generally about 80% of STC, the full system derate, including temperature losses, is commonly around 70%.

Deciding on how large a PV array to connect to the inverter requires predicting output over the course of a year. Generally, PV arrays produce less than their STC rating, due mostly to conditions that differ from STC—like higher cell temperatures, lower irradiance, and module soiling. When predictable system losses are taken into account, a PV system owner can expect their array to operate at around 80% of the STC rating. Since these losses are consistently present, the size of the PV array can be designed to exceed the inverter's power rating.

Many inverter manufacturers specify simply that a PV array's STC rating should be no more than 125% of the inverter's continuous output rating—known as the “sizing ratio.” For example, if an inverter has a continuous output rating of 5,000 W, the maximum array size that would be connected using a sizing ratio of 1.25 would be 6,250 W (5,000 W × 1.25).

While this is a handy rule that covers a wide range of installations, it doesn't deal with when the PV array is able to produce more power than what the inverter can process. This can happen when the array is operating in a cold and sunny environment, which will make output higher than usual. If the inverter is already operating at its maximum, the total power output will be limited.

Given that the inverter's cost in the entire system is relatively low, most PV designers apply a more conservative sizing ratio, like 1.10 to 1.15 (10% to 15% above the

inverter's output rating). In most climates, this allows your inverter to process the PV array's power without clipping the power output for most of the time. Some PV designers match the PV array's STC rating to the inverter's output rating (a sizing ratio of 1.0). This makes sense for sites with commonly cold temperatures and higher irradiance (like at higher elevations), practically removing the inverter as the limiting factor, except for brief times when the array output goes beyond STC rating, like from the “edge-of-cloud” effect.

## DC Voltage Ranges

After the inverter's power output rating has been considered, the choices can be further narrowed down based on brand preference. You can then refine the list even more by determining the maximum and minimum number of modules allowed in a string. Inverter manufacturers always list the maximum allowable input voltage and the required maximum power point tracking (MPPT) range for their inverters' operation. Make sure the array never exceeds the inverter's maximum voltage and remains above its minimum voltage during operation.

Manufacturers report multiple voltage values, but focus on two: the maximum input voltage and the minimum MPPT voltage. These two extremes will define the DC voltage window. Remember that module voltage is inversely affected by the PV cell operating temperature—the higher the temperature, the lower the voltage and vice versa. The cell temperature is related to the ambient air temperature.

All inverter manufacturers maintain string sizing calculators on their websites. In addition, Blue Oak Energy and *SolarPro* magazine offer an online string-sizing tool (see Access). A good design practice is to perform the calculations manually and then use Internet resources to double-check your work.

The maximum input voltage an inverter can accept is the limit of the temperature-adjusted open-circuit voltage (Voc) of the PV array. This voltage is critical—if the array exceeds it, the inverter can be damaged. The other voltage parameters are the upper and lower ends of the MPPT window.

The array's temperature-adjusted MPP voltage (Vmp) must always remain above the inverter's minimum MPPT value while the array is operating, or the inverter may shut down and not go back on until the next morning—when the cooled-down array starts making energy again. For a good review of Voc, Vmp, maximum power point, and other PV-specific electrical parameters, see “Back Page Basics” in *HP131*.

Keeping the array's voltage outputs within the voltage window for all temperature conditions will help ensure the inverter won't be damaged or turned off during extreme temperature conditions. There are some generally accepted rules that most designers can agree on (see “Accounting for Photovoltaic Cell Temperature” sidebar at right).

Unless the inverter has multiple MPPT, all the module string lengths should be identical and should have the same orientation. While it may be possible to have strings at different tilt or azimuth angles, it isn't ideal.

# Accounting for Photovoltaic Cell Temperature

During the design phase, you will need to estimate the temperature of the PV modules to determine the temperature-adjusted voltages from the array. The exact values to use will be based on the array location, the proximity of the array to a structure (such as a roof), and the designer's own estimation of ambient temperatures.

For adjusting the array's Voc value, use the record low temperature as the minimum PV cell temperature. The array will go to full Voc once the sun strikes the array and before the array has begun to warm up. This is a conservative estimate, justified because high DC input voltage can damage an inverter.

There is a little more latitude when designing for the Vmp of the array—components won't be damaged, but the inverter runs the risk of shutting down. Once the PV cells have been sitting in the sun, they will be hotter than the ambient air temperature. Cell temperature estimation typically relies on using either the highest average temperature or the record-high temperature in your location.

Another method is to use the American Society of Heating, Refrigerating and Air-Conditioning dry-bulb temperature data (Appendix E of *Expedited Permit Process for PV Systems*—see Access). The appendix shows a "2% design temperature," where the recorded temperature exceeded the listed value 2% of the time, averaged from June through August. If you use this data, the result is an accurate PV cell temperature estimate for 98% of the summertime conditions. This is acceptable, considering there will be little time when the array operates at a higher temperature, which may result in inverter shutdown, but does not result in inverter damage.

## Example ASHRAE 2% Design Temps

State	City/Station	°C
AZ	Phoenix	43°
CA	San Francisco	28°
CO	Denver	33°
IL	Chicago	33°
NC	Charlotte	34°
NJ	Newark	34°
TX	Houston	36°
WA	Seattle/Tacoma	29°

The final method is estimating the cell temperature for high ambient-temperature conditions. This considers the ambient temperature, as well as the PV array mounting method. As with the ambient temperature selection, this is not a set value but ranges from adding 25°C to 35°C to the ambient temperature (see "String Theory" in *HP125*).

## Voltage Correction Example

To help clarify, here are example calculations for adjusting the two module voltages. The example module has the following specifications:

Voc = 33.6 V

Temperature coefficient for Voc = -0.114 V/°C

Vmp = 26.4 V

Temperature coefficient for Vmp = -0.124 V per °C

The site has a record cold temperature of -18°C, so for adjusting Voc, this temperature will equal cell temperature.

To calculate the adjusted voltage for cold temperatures, use the equation:

$$V_{oc \text{ at STC}} + ((T_{cell} - T_{STC}) \times \text{coeff}) = \text{Max } V_{oc}$$

$$33.6 \text{ V} + ((-18^\circ\text{C} - 25^\circ\text{C}) \times -0.114) = 38.5 \text{ V}$$

The 2% summer temperature is 37°C and the array is mounted parallel to the roof so the module's high cell temperature is estimated at 37°C + 35°C = 72°C. To calculate for the adjusted Vmp value in the summer:

$$V_{mp \text{ at STC}} + ((T_{cell} - T_{STC}) \times \text{coeff}) = \text{Min } V_{mp}$$

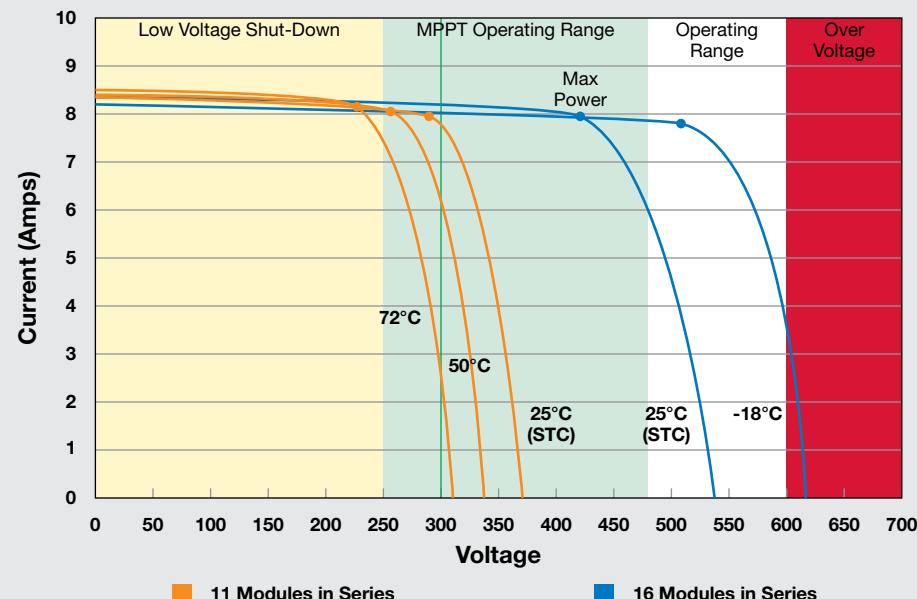
$$26.4 \text{ V} + ((72^\circ\text{C} - 25^\circ\text{C}) \times -0.124) = 20.6 \text{ V}$$

These new adjusted voltage values can now be used to calculate the minimum and maximum number of modules required by a particular inverter. For example, if a SMA SB5000US inverter was chosen, the inverter can accept up to 600 VDC and requires at least 250 VDC to operate. Using the example modules:

600 VDC ÷ 38.5 Voc = 15.5 modules, or a maximum string length of 15 modules

250 VDC ÷ 20.6 Vmp = 12.1 modules, or a minimum string length of 13 modules

## Cell Temperature & Inverter Operating Range





**Combiner boxes, like this one from OutBack Power Systems, provide necessary overcurrent protection for the array.**



**A transition box can be used to change wire types and sizes on the roof.**

## DC Input Strings

Once the inverter has been selected and the module strings have been determined, the next consideration is how to get the PV circuits off the roof and to the inverter. Typically, there will be a junction box near the PV array. Since most PV modules come with cables with quick connects, this box can transition from the outdoor-rated conductors used at the array to properly rated conductors in conduit. The box can also be used to combine the PV source circuits and run to the inverter with a single circuit.

Since it's possible to see PV arrays with four strings serving a single inverter in residential applications, whether to combine or not deserves attention. If the circuits were to remain separate, that requires running more conductors. More conductors in conduit requires derating the conductors because of additional heat inside the conduit. The benefit of using separate circuits is to utilize the disconnect/combiner that is part of most residential-sized grid-tied inverters—saving time and money on additional boxes. And even with the additional conductors, in a typical four string residential application, you can still install 10 or 12 gauge conductors in 3/4-inch conduit.

The option of combining strings at the array should not always be dismissed, though. It comes down to analyzing the cost differences between the two methods. For those systems under the 2011 *NEC*, be aware that there is a change that requires a disconnecting means at the combiner boxes for fuse servicing. This may preclude the use of combiners in many residential applications since there isn't always a good location on roofs.

## AC Voltage Window

The AC operating voltage range for all UL 1741 grid-tied inverters is relatively narrow. Inverters can operate from 12% below to 10% above nominal grid voltage (211 to 264 V for a 240 VAC system).

In the majority of installations, voltage drop between the inverter and the grid isn't an issue. But if the conductors between the inverter and the main distribution panel (MDP) are too small, the inverter will interpret the grid voltage as being out of spec (greater than the nominal voltage +10%). The inverter's automatic safety features will isolate it from the grid while it waits for the voltage to get back into spec.

Ideally, the voltage drop in the conductors between the inverter and the MDP will be less than 1.5%, to give the inverter the best opportunity to stay connected to the grid in all situations. Calculating voltage drop before specifying conductors is wise—upsizing conductors after they have been installed is never fun or easy.

## Other Considerations

This article will help you size the right inverter for your array, but does not cover every aspect of system design. Other factors, such as the maximum AC overcurrent device you can connect to; acceptable wire sizes; the inverter's temperature limitations—both high and low for outdoor locations; monitoring options; and warranties will play a role in shaping your system. Consider all aspects of your system design to make an educated inverter choice.

## Access

Ryan Mayfield (ryan@renewableassociates.com) is a NABCEP-certified PV installer and ISPQ Affiliated Master Trainer. He is anticipating the long days of spring and summer with their increased solar resource and opportunities to root for his favorite baseball teams.

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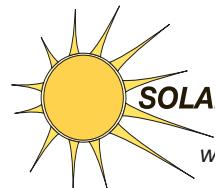
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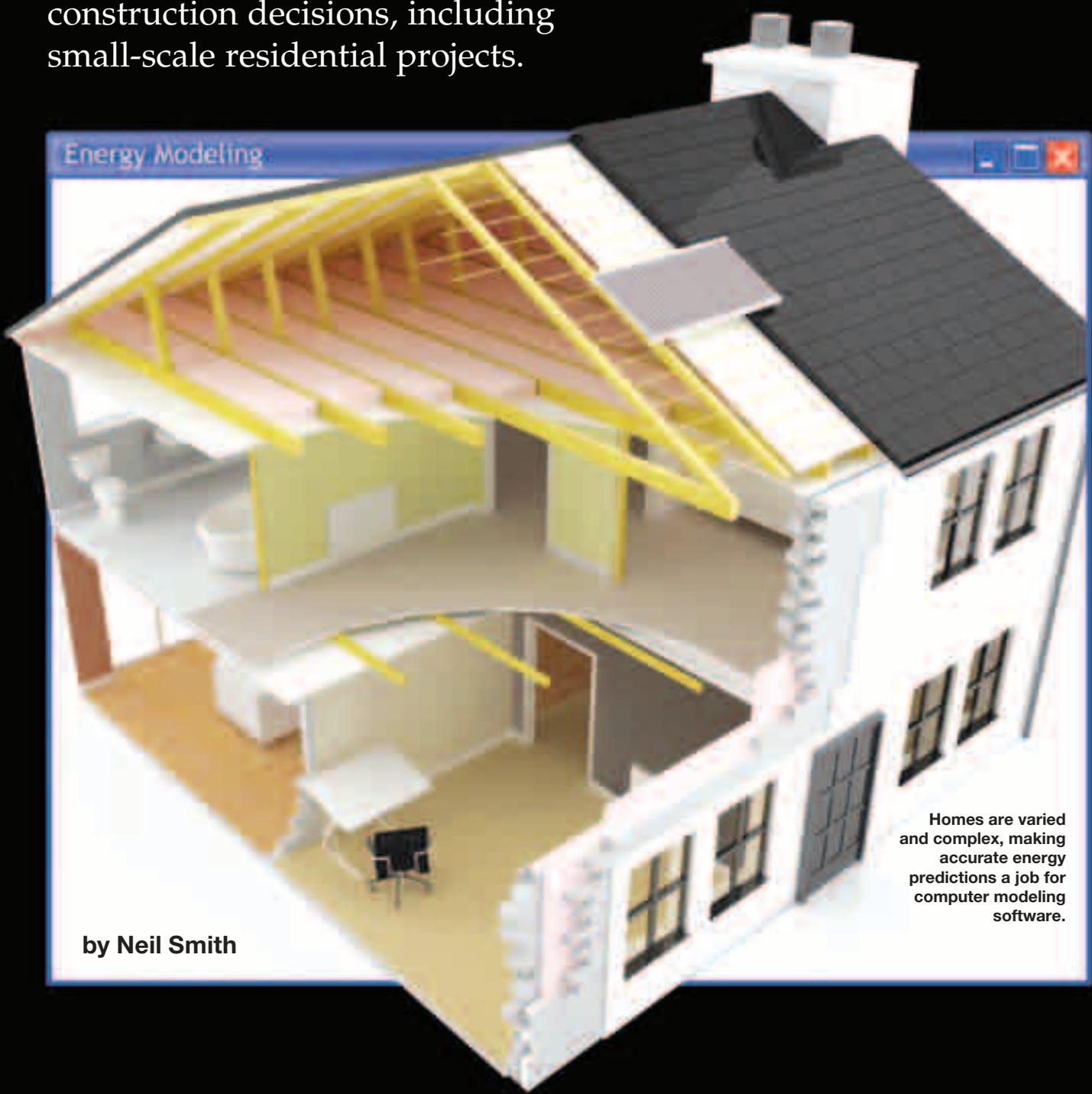


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# High-Tech Home Energy Assessment

Get your geek on—energy modeling is poised to play a large role in construction decisions, including small-scale residential projects.



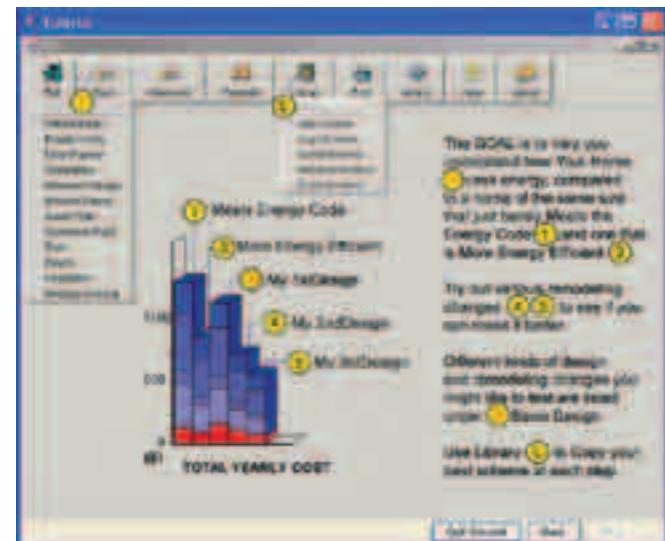
Homes are varied and complex, making accurate energy predictions a job for computer modeling software.

by Neil Smith

**E**nergy-modeling software is more accessible than ever. Good thing—many incentive programs now require scientific validation to “prove” a home’s energy performance before you can cash in. From a builder’s and homeowner’s perspective, and short of actual construction, modeling is the most accurate method of comparing building designs. You get to test-drive your designs and tweak them in response to the results, saving yourself from expensive design disasters and a poorly performing house.

Building simulation computer software can model a home’s year-round energy performance. The goal of a simulation is not only to predict how much energy a building will use, but also to compare alternate designs. These programs also allow you to investigate source-energy consumption and carbon dioxide production. Sophisticated software can even predict the number of hours that the building will be outside of the human comfort zone.

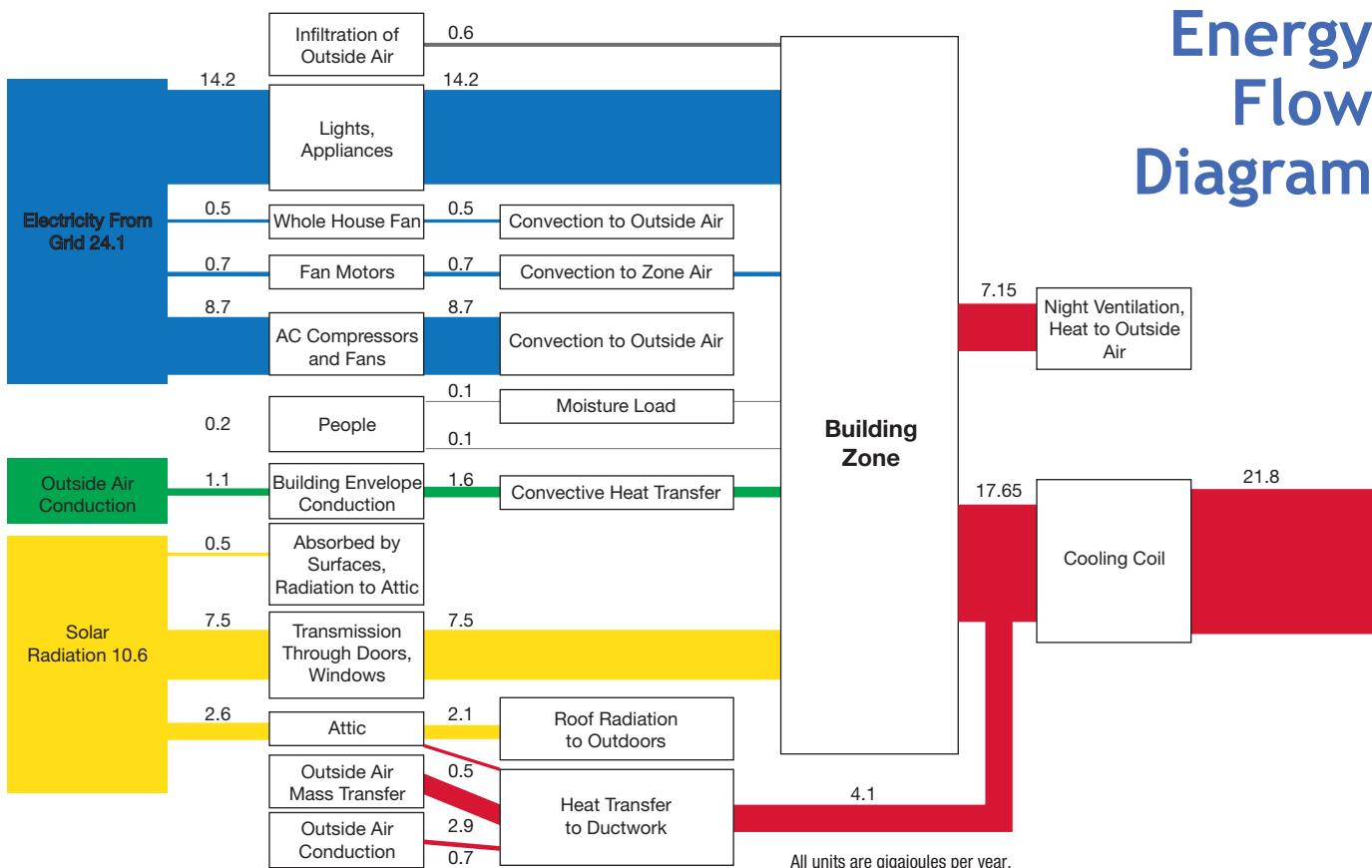
The energy flow (Sankey) diagram illustrates the complexity of energy flows for a typical house. Based upon a building description that is input by the user, the software calculates all the energy flows, including the thermal effects of people, infiltration, lights, and other loads. The flow of energy is further complicated because building materials are not just insulators; they also have a certain heat-retention capacity. Everything from furnace efficiency and fan performance to daylighting controls and heat loss can be simulated on a continual, year-round basis.

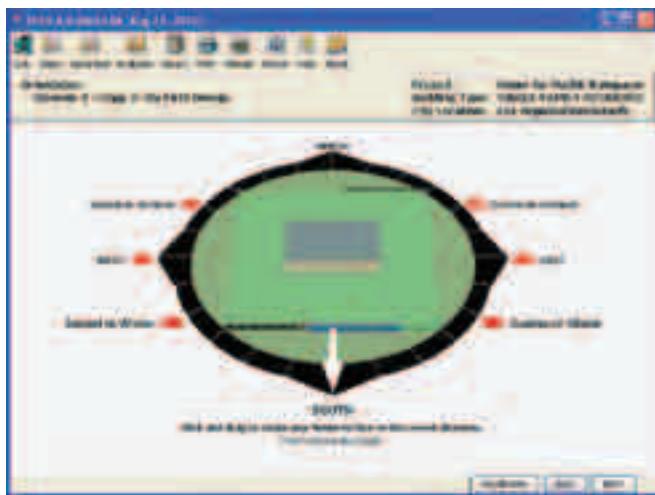


Some building simulation software, like HEED, includes tutorials to help users input information correctly.

### User Benefits

With all this data, it’s clear that a simulation can be very helpful with building design decisions. Authorities that regulate energy compliance and agencies that give out rebates want to see this kind of analysis to make sure that buildings qualify.





Most building simulation programs allow users to input data on their home's orientation to assess solar gains and losses.

Quickly and accurately comparing various ways of building, different equipment, and even alternate control strategies, yields a much better chance of optimizing building envelope and systems based upon the actual climate, planned use, and economics.

Besides analyzing the all-important design day, which represents the climatic conditions that yield the highest thermal load (also known as peak load), nonlinear system effects may be revealed—where simple changes yield complex effects. Nonlinear means that many of the house's energy inputs are not proportional to their loads. For example, if you double the cross-sectional area of all the ductwork, then the (theoretical) fan power decreases to one-quarter of the original. In turn, the fan motor heat is reduced. Even without increasing duct size, if airflow is reduced by half, the software predicts that our fan power should reduce to  $1/8$  of the original.

Computer simulations examine alternatives such as increasing or decreasing mass, using equipment with better unloading capabilities, and oversizing systems that would otherwise be evaluated only by an educated guess. Before you drive one nail, you can optimize your design, leading to savings in time, labor, materials, equipment, and energy.

## Software Genesis

To design heating, ventilation, and air-conditioning (HVAC) systems that provide comfort and economy, engineers have always relied on calculations to predict heating and cooling loads. When cheap computing power became available, hand calculations were automated. As computers became more powerful, more sophisticated and accurate algorithms replaced approximation methods.

Commercial simulation software offers a great deal of programming flexibility. With that flexibility comes many choices, and a steep learning curve. Because these tools offer so much potential, there is a lot of activity focused on making the software more accessible by offering graphical interfaces and building model templates.

Simulation software uses the physics of heat transfer combined with environmental conditions to determine internal temperatures and heat flows. This is the calculation "engine," which can use various load calculation methodologies, with most of the differences usually only of interest to researchers. Although the software is very complex, conceptually there are three main sections:

- Describe the building
- Define the thermal zones
- Define the mechanical system

## The Building Model

In this phase, the task is to take all the details of a building and input the parameters into the software. For the building envelope itself, the order of information is:

- Location
- Weather file
- Orientation
- Surfaces
- Doors, windows, and walls
- Materials
- Material properties

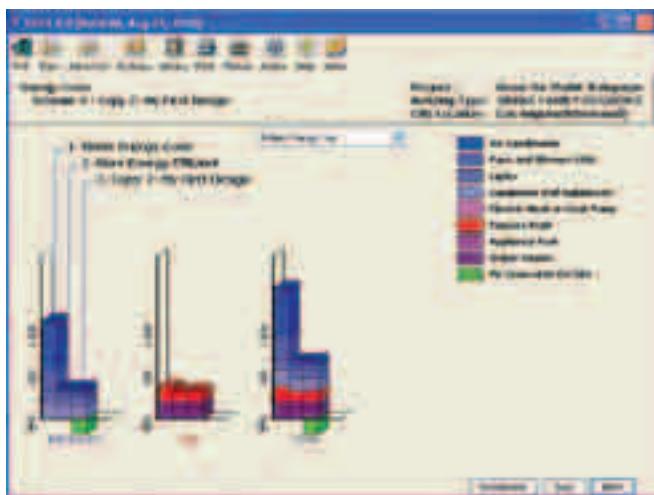
Then we do the same for interior surfaces, since even with a single-zone model they can affect the building's thermal performance and capacity.

Because internal loads—such as people, lights, set points, and the schedules that govern them—can also influence the building envelope, they need to be included. To describe these loads, which vary over time, we use the concept of "schedules." An example would have inputs for time, day of the week, and holidays so that the software will be accurate any time of the year and determine what the setpoint should be, or how many people are expected in the zone, or any other event you wish to model.

## Open-Source Software

Although much of the software discussed has been developed with public funding, none of it is open source, which allows anybody access to the underlying software code. The beauty of open source is that users can customize the code to their own needs, find errors, or even offer improvements. Most open-source licenses enforce this spirit of collaboration by requiring any redistributions of the code to also be freely available. Some notable examples of open-source software include Firefox (browser), Linux (operating system) and, lately, Android (mobile phone operating system).

What does this mean in terms of modeling software? Without open-source capabilities, it means that the code is largely hidden and customizing the software is difficult, if not impossible.



Built-in “reference” homes make it easy to see how your home design measures up in terms of energy efficiency.

## Thermal Zones

Buildings are divided into thermal zones. A zone is defined as the space controlled by a single temperature controller. Residential systems typically have only one thermal zone, controlled by a single thermostat. This is where the model loses some accuracy, since different rooms in a house can be comparatively cooler or warmer. The justification for this thermal control and modeling inaccuracy is that occupants

often move based on comfort. If the bedroom is cold but the sun is shining through the living room windows, just like Fluffy the cat, we can relocate ourselves to that sunny spot on the couch. For modeling purposes, specifying an average temperature is usually good enough.

Once this part of the model is complete, the software can calculate the “loads” by applying the physics of heat transfer, which are incorporated into algorithms for heat conduction, radiation, and convection. The simulation engine churns through millions of such calculations to determine the cooling and heating loads for every hour of the year. Each calculation uses all of the previous inputs, including climate, building envelope, and schedules (occupancy and setpoints) to determine the energy required to maintain the temperature set point—the target value of a controlled parameter. (For example, a room temperature set point would be 70°F for heating and 74°F for cooling.) The weather is simulated by applying a full year of climate data for the home’s location, which can include temperature, humidity, and cloud cover.

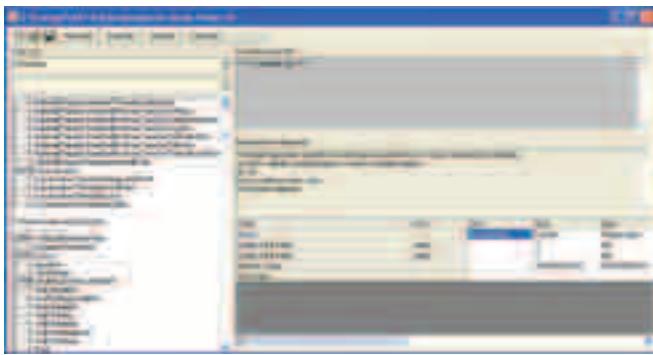
## Mechanical Systems

Just as your car does not deliver its best fuel efficiency when you’re stomping on the gas, a mechanical system does not deliver the same performance or efficiency under varying conditions. In this phase of the simulation, the software uses the calculated thermal load and the characteristics of the mechanical equipment to determine the equipment’s response (on or off, fan speed, etc.).

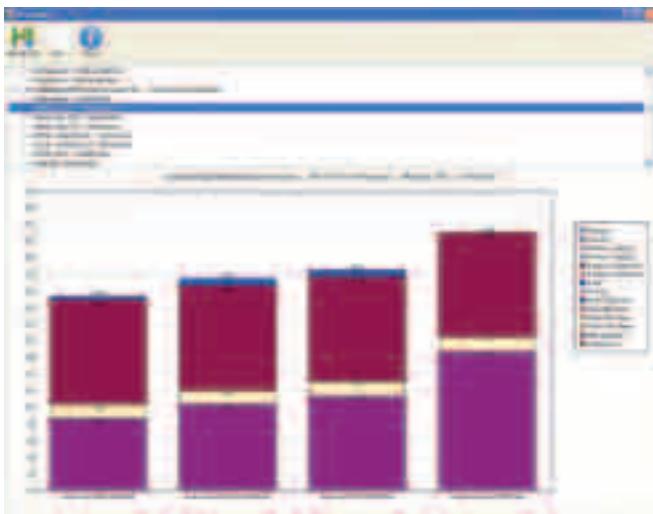
## Selected Residential Energy Modeling Software

Software	Types of Buildings & Systems	Graphical Interface; Ease of Use	Calc. Engine; Suitable for Pro Use	Add-on Software	Support	Notes
<b>HEED</b> <a href="http://www.energy-design-tools.aud.ucla.edu">www.energy-design-tools.aud.ucla.edu</a>	Simple residential structures & mechanical systems	Yes; Easy	DOE2; No	No	Via e-mail	Great starter, may meet all your needs. Meaningful comparisons for small amount of work. Fast output, limited to simple structure and mechanical systems. Good source of articles written in understandable language.
<b>EnergyPlus</b> <a href="http://gundog.lbl.gov">http://gundog.lbl.gov</a>	Any; allows custom components and systems	No; Difficult	EnergyPlus; Yes	Plug-in for Google Sketch-Up, 3rd party GUIs	Extensive manual. Active mailing list. Courses available.	Almost everything can be modified and interfaced with. Can be used to size equipment and air flows.
<b>Equest</b> <a href="http://www.energydesignresources.com">www.energydesignresources.com</a>	Any, but limited when modelling non-standard systems.	Yes; Moderate	DOE2; Yes	3rd party interfaces and GUIs	Large manual. Active mailing list. Courses available.	Based upon DOE2.1
<b>DOE-2</b> <a href="http://www.doe2.com">www.doe2.com</a>	Any	No; Difficult	DOE2; Yes	3rd party interfaces and GUIs	Large manual. Active mailing list. Courses available.	One of the first pieces of sophisticated simulation software

Note: For more building energy software tools and information, see [http://apps1.eere.energy.gov/buildings/tools\\_directory](http://apps1.eere.energy.gov/buildings/tools_directory).



**Attention to detail is critical when entering data on the home's various systems. The more accurate the information, the more accurate the results.**



**Results presented in graphical format make interpreting and comparing modeling results much easier.**

The mechanical system's response to a call for heating or cooling is not always as expected. In a commercial system, a zone call for cooling can set off a chain of events, from increased local air flow to increased speed of a fan, to more cold water from a chiller. To correctly model energy usage, the software has to predict the interactions of all these pieces of equipment as they attempt to do their job. If the equipment has been modeled correctly, we can learn a lot.

Most of the time, equipment operates below its maximum capacity, otherwise known as "part-load" conditions or "partial loading." Part-load performance can be more important than full-load efficiency in determining annual energy use. An example of how researchers have attempted to document this is the Seasonal Energy Efficiency Ratio (SEER), which gives the efficiency of residential air-conditioning units as a weighted average under different outside air temperatures. But an energy simulation is much more accurate in predicting energy use than such a one-size-fits-all parameter.

### Choosing Software

The Department of Energy's free EnergyPlus software is probably the most technically deep software—with a

## Test-Driving EnergyPlus

Taking modeling software for a test-drive is the only way to get familiar with the software. I tested three houses in EnergyPlus, each identical in terms of construction, orientation, occupancy, set points, etc. The weather locations are Boston, Sacramento, and San Jose, California. Basic parameters were:

- 60 by 40 ft. footprint
- Wall system: 2-by-4 wood frame, with wood siding, drywall and R-13 fiberglass insulation
- Glazing equally distributed on each facade
- Attic with R-38 fiberglass insulation
- Concrete slab-on-grade

This round of simulations focused on reducing electrical cooling energy, so the model was done for May through September. For each house/location, I added the following variations (cases):

**Case 1**—Base: Air-conditioning

**Case 2**—Base + small whole-house fan

**Case 3**—Base + small whole-house fan + phase-change material

**Case 4**—Base + large whole-house fan

**Case 5**—Base + large whole-house brushless, permanent-magnet motor fan + phase-change material

For the phase change material (PCM) scenarios, I used PCM embedded in the drywall for exterior walls and ceilings (see "Phase Change Materials" sidebar).

3,000-page manual, it's considered the Swiss army knife of simulation software. Plus, it's free to download.

If you want less of a learning curve, simpler software with fewer building parameters may be a better choice. Many of the packages use a graphical interface, which makes the initial building description phase straightforward. The Home Energy Efficient Design (HEED) software is particularly easy to use, designed for residential applications and incorporates energy-saving strategies into its design alternatives.

Remember that your results will only be as accurate as the data you supply. Inaccurate data in equals inaccurate data out, so make sure you check and double-check your input parameters.

The purpose of the runs outlined in the "Test-Driving EnergyPlus" sidebar was to get an overview of which systems and strategies were worth further investigation. In particular, the hunch was that phase-change material, which is great for load shifting, would work synergistically with night ventilation. Cooling set points were set at 73.4°F. Each case has air-conditioning, however, cases 2 through 5 have the mechanical cooling system disabled from 7:00 p.m. to 12:00 p.m., and depend upon either night ventilation or thermal capacity for cooling at those times.

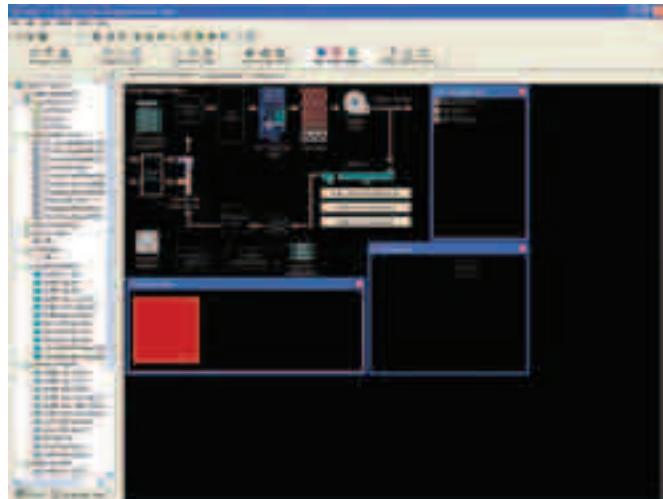
## Phase Change Materials: The Future for Retrofits?

Phase change materials can store and release the large amount of heat required to change from solid to liquid phase. The energy required to melt a material (latent heat) is much higher than the energy to raise the temperature of the material (sensible heat). As the material is being melted or frozen, the temperature remains the same. In contrast, a concrete wall will absorb a lot of heat, but its temperature will change in doing so.

The simulations run for this article use PCM-impregnated drywall, which has a thermal capacity of 22 Btu/ft.<sup>2</sup> (while remaining constant at 77°F). A 6-inch-thick concrete wall would have its temperature change by 1.5°F to absorb the same amount of heat. There are other subtle differences in how each thermal capacitor performs. For instance, the thickness of the material affects how quickly its average temperature changes due to internal resistance.

If you are designing a new structure, it will most likely be less expensive to build-in thermal capacity by placing high-mass materials such as concrete in contact with the building's interior. However, for retrofits, adding a concrete wall, floor, or ceiling may not be practical. That is why building scientists are so interested in phase change materials.

If we are interested in storing heat or cooling, we can store much more energy per volume or mass with PCM than with sensible heat. Ever wonder why air conditioning is rated in tons? It takes 1 ton of cooling running for 24 hours to freeze 1 ton of water.  $2,000 \text{ lbs.} \times 144 \text{ Btu/lb.} \div 24 \text{ hours} = 12,000 \text{ Btu/ hr.} = 1 \text{ ton AC.}$



Some modeling programs offer a high degree of visual sophistication to help users correctly configure the home's systems.

## Results

As expected, the modeling showed that night ventilation via whole-house fans used less energy for each of the selected climates. Increasing the thermal capacity by adding PCMs helped reduce cooling costs. However, the best savings resulted from using PCMs with a large, brushless permanent magnet-motor-equipped fan. Interestingly, using the large whole-house fan (case 4) saved less energy than using a smaller fan. This appears to be due to the fan using nearly as much energy as it saves. A better model using a more realistic control sequence (as a smart homeowner would do, using fans depending on comfort) seems like an interesting area of inquiry.

Each of the runs also provides a "comfort report" showing the number of hours that are outside of the comfort model. There are virtually no uncomfortable hours for the San Jose location; Sacramento cases averaged 120 hours, while the Boston climate reflected up to 180 hours that did not fit within comfort standards. A next step might be to refine the energy models for a particular climate by using more sophisticated controls to optimize comfort and economy by deciding when to use mechanical cooling or night ventilation.

## Valuable Tools

Energy simulations are great tools for building and designing energy-efficient buildings. Creating a basic model can be very quick and effective to address basic building and mechanical system design issues. If time permits, there is even more opportunity to optimize the building envelope, siting, shading, and mechanical systems. Plus, these tools are certainly more powerful and offer much more insight and validation than some "point systems" that are commonly used to determine energy compliance.

## Access

Neil Smith (neil@airscapefans.com) is a professional mechanical engineer. Neil's interests include HVAC and energy efficiency, and he currently runs the AirScape whole-house fan company.





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# Heading for ZERO

## Smart Strategies for Home Design

by Jim Riggins

Our goal was straightforward: build a net-zero energy house, emphasizing passive features, while minimizing the environmental impact both during and after construction. While we weren't seeking formal certification, this house followed the German *passivhaus* design philosophy of combining a super-insulated and air-sealed shell with passive solar design to reduce heating loads. Combined with using only Energy Star-rated appliances and solar water heating, computer modeling predicted this all-electric house, dubbed Heliospiti (Greek for "sun house"), would achieve net-zero annual energy input by adding a 4-kilowatt (kW) PV system.

### Where to Begin

To start the energy modeling and design, my wife Elise and I defined the basic features of the house:

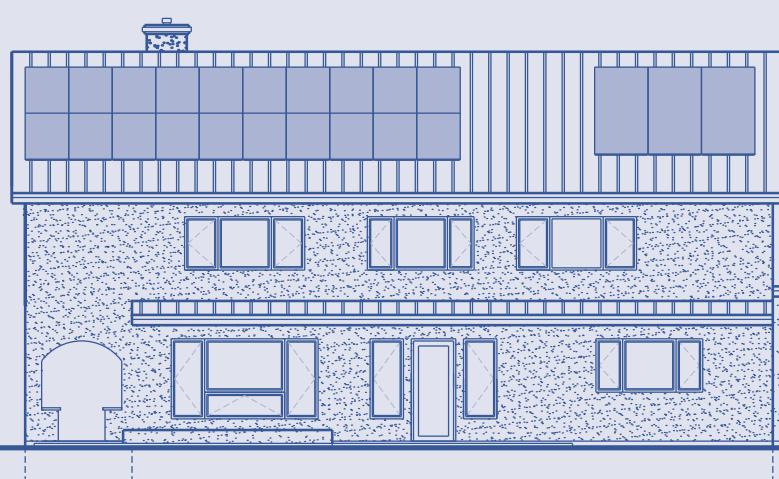
- A floor plan that would be spacious enough to accommodate our two children, but small enough to be an "empty nest" home, with no wasted interior space.
- An open interior to avoid wasted space and promote airflow through the house.
- Slab-on-grade design with the concrete slab as our main floor and the thermal mass needed for passive solar.
- Two-story, rather than ranch style, to maximize the house's volume-to-surface area ratio, and minimize thermal loss.

- Rectangular shape with long east-to-west axis to maximize solar gain and daylighting.
- A garage that would share minimal wall area with the main house to reduce the risk of harmful fume migration into the living area.
- Defining the thermal boundary at the roof, not the attic floor, for ease of air sealing and to keep the attic as a semi-conditioned mechanical room.
- Compliant with the Environmental Protection Agency's WaterSense guidelines to minimize water consumption.

### The Energy Design

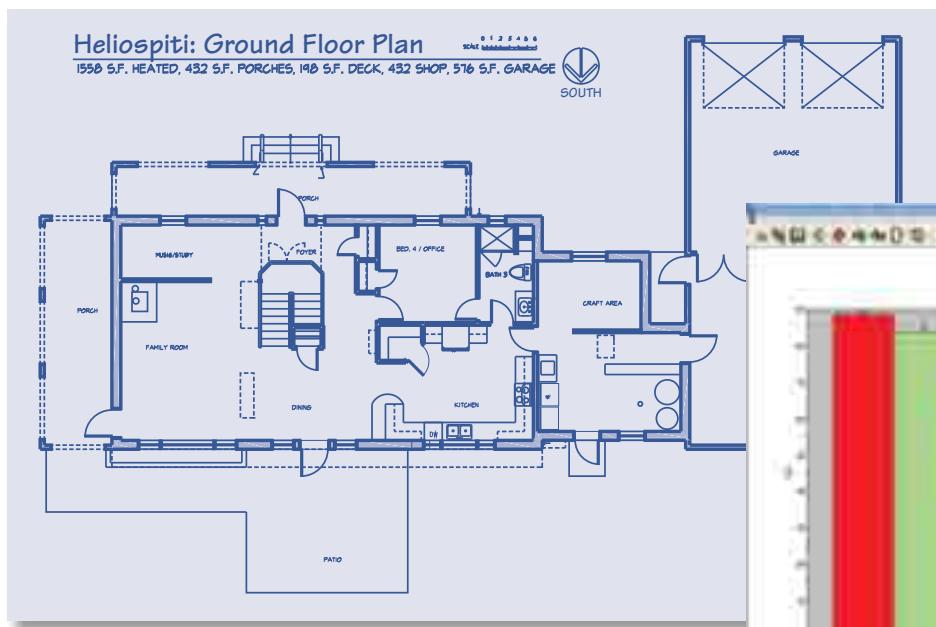
With a basic idea of what we wanted, we turned to Debra Rucker Coleman's book, *The Sun-Inspired House*, for the fundamentals of passive solar design (see "Designing Your Place in the Sun" in *HP116*). On her website, we found a design very close in size and floor plan to the house we had already sketched out. That set our architectural design path—we bought those plans, and set about modifying them to go from high-efficiency passive solar to net-zero energy.

Since I owned Energy-10 software for my consulting business, we had the tools already at our fingertips. Designed by the National Renewable Energy Laboratory (NREL), Energy-10's hour-by-hour simulation capability and extensive NREL validation make it excellent for capturing the complexities of passive solar design. This all-in-one software



**Heliospiti: South Elevation**

South-Facing Glazing 8.5% of Total Floor Area



**Below:** Energy-10 software can predict heat gain and loss, emissions and financial payback.



costs \$375; but a set of mostly free, component-by-component analysis tools can be found on the Department of Energy's website (see Access).

We began with a bioclimatic assessment of our climate (see "Be Cool—Natural Systems to Beat the Heat" in *HP108*). The assessment showed our Colorado climate, with its low humidity and cool summer nights, to be well-suited to passive cooling in the summer and passive heating in the winter. We planned to use natural convection to passively cool by including low windows on the first floor and high windows on the second, both of which would be opened at night. Warm air moving out the upper windows would draw cool air across the thermal mass. Excellent resources for historical local climate and solar data are found at the National Weather Service and the NREL PVWatts program (see Access).

For parametric studies, we modeled a reference home of the same size and shape of the Sun Plans design, and proper southerly orientation for our Monument, Colorado, location. The reference house was standard 2-by-4 construction, with an R-30 insulated ceiling. From there, we changed one parameter at a time to explore its impact on the home's overall energy consumption.

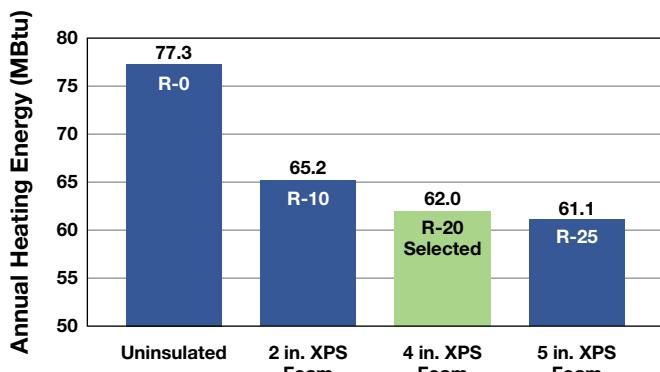


## Efficient Construction & Materials

This article focuses only on the energy design of our home, Heliospiti. It does not cover the efficient construction techniques and green products we used, which includes everything from minimizing site impact and recycling construction materials, to eco-friendly countertops, floors, paints, and cabinets. For the construction, we followed the Built Green checklist and the Green Building Guidelines from the U.S. Department of Energy (see Access).



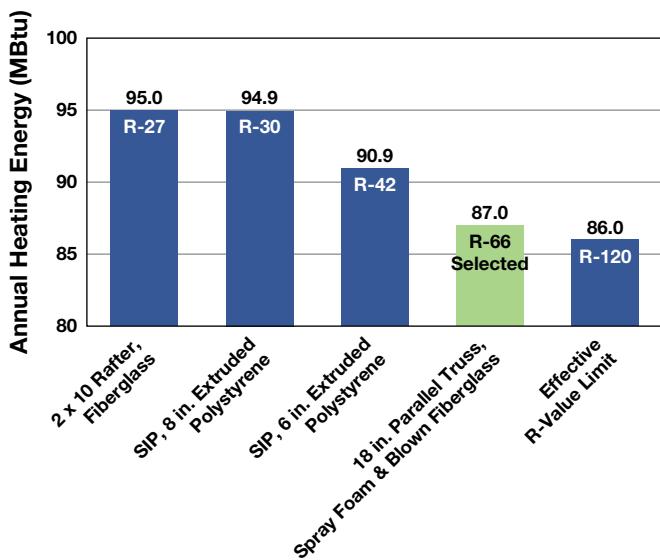
## Slab Insulation



**Slab insulation** analysis came first and the resulting graph shows the change in annual heating energy for incrementally higher levels of perimeter and under-slab insulation. The slab thickness is fixed at four inches to balance thermal mass and thermal lag. As shown, the impact of slab insulation is greater from R-0 to R-10 and begins to level off at R-20. As a balance between cost and performance, we chose R-20 for both the perimeter and under the slab.

**Wall analysis** was next, with worst-case scenario being fiberglass-batt-insulated, 2-by-4 frame wall (R-13). The upper limit is shown by an R-120 value. Most of the initial modeling runs were for structural insulated panels (SIPs), both polyurethane (PUR) and expanded polystyrene (EPS) of varying thicknesses. The 2-by-6 wall was modeled using R-19 fiberglass batts in 16-inch-wide stud cavities, plus 1 inch of rigid polyisocyanurate foam on the exterior surface for R-23. Our initial preference was to proceed with 6-inch-thick SIPs, but like other decisions, this would change later when we factored cost into the equation.

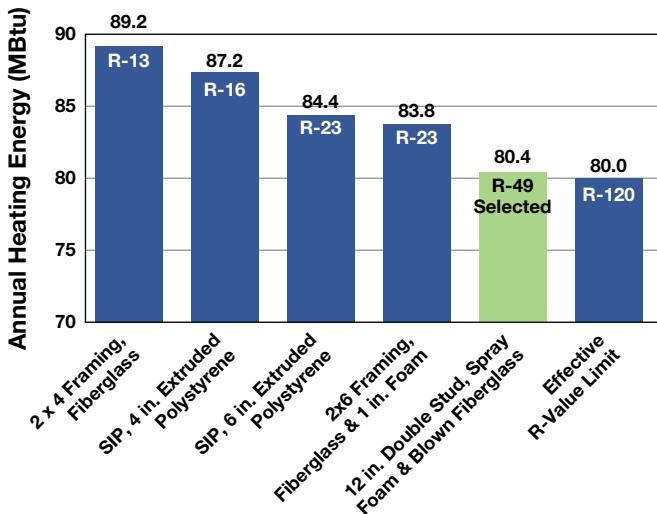
## Roof Construction



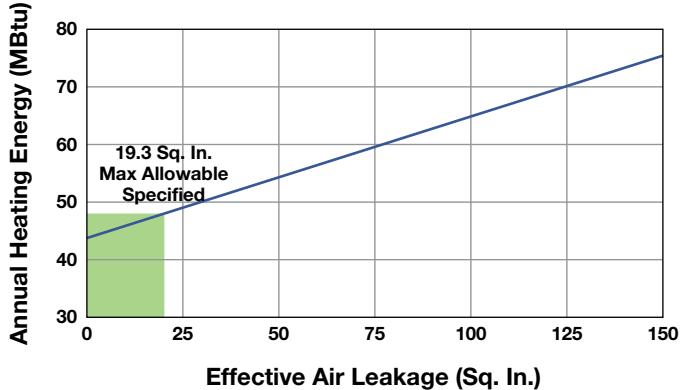
**Roof analysis** was similar to the walls with its hypothetical R-120 value for an upper limit. We could not meet our R-60 roof goal with SIPs. The highest-performing panel, a 12-inch-thick extruded polystyrene, reached R-57 and was significantly more expensive than other alternatives. We transitioned to a new plan—a parallel truss system.

**Sealing.** A home's overall energy performance is affected heavily by air leakage, and the analysis confirmed this. One needs to place as much (or more) emphasis on air sealing as on insulating. Energy-10 plots heating energy use against several “effective leakage areas” (ELAs), to visualize the impact. To ensure the house met its performance goals, we had written into our construction contract the requirement for a blower-door test (before drywall is installed), with a maximum air leakage of 350 cubic feet per minute at 50 pascals of pressure—the equivalent of 19.3 square inches of effective leakage area (ELA). This was a compromise between an extremely tight envelope and what is realistically achievable. By comparison, the typical house in the United States has approximately 165

## Wall Construction



## Air Leakage



square inches of effective leakage area. Although our target is an aggressive air leakage limit, the passive house community has shown that even more stringent limits can be reached. Of course, this level of air-tightness necessitates mechanical whole-house ventilation.

**Window analysis** was more complicated because of the various parameters involved: window size, glass type, frame and sash material, orientation, surface area, and shading. It is easiest to analyze shading first and separately, and then work on the other parameters.

Great resources for shading analysis are the tools found at the Sustainable By Design website. Using their Window Overhang Annual Analysis tool, we selected an overhang depth of 2 feet, with 5- to 6-foot-tall windows starting 1 foot below the overhang. This gave us a good balance of winter solar gain and summer solar shading.

Selecting and analyzing the window type and performance is the nightmare of passive solar design. The “magic window” of very high solar heat gain coefficient (SHGC) to heat the thermal mass and very low U-factor (thermal transmittance) simply does not exist. For passive solar performance, we wanted south-facing glass that let in as much solar heat as possible in the winter and trapping as much of that heat as possible for night. Because SHGC tends to decrease as U-factor decreases, the goal of the analysis is to find the SHGC/U-factor combination that produces the lowest heat load for the specific climate—and still be able to afford those windows!

A great source of third-party ratings on windows is the National Fenestration Rating Council website (see Access). Using their data, plus speaking to window manufacturers, provided a wide range of window specifications for modeling. We narrowed our focus to fiberglass frames because of their excellent thermal performance in temperature extremes. Our average minimum temperature is 17°F and average maximum is 85°F, but the record low is a bone-chilling -27°F.

The window analysis graph shows a sample of the dozens of south-facing glass and window combinations that we analyzed. Down to a certain point, the solar heat gain was more important than thermal resistance. However, when you get to the very low U-factors available with some coatings,

## Solar Takes It to Zero

Passive and active solar technologies helped us meet our goal of a net-zero energy home.

Based on a detailed appliance-by-appliance analysis, including a charging station for a future electric vehicle, we calculated that a 4 kW PV system would take us to net-zero energy. For appliances not yet owned, we found the actual models we wanted and used consumption data from the Energy Star database. We used the actual data for the well pump, air-source heat pump, and the energy recovery ventilator. Then, we padded the load analysis a little for things like data monitoring and logging equipment. Working with a system installer, we decided upon 20 Sharp ND-224 PV modules, each matched to an Enphase M-190 microinverter—4.48 kW total.

We predicted hot water consumption based on our actual usage patterns, and converted gallons per day to Btu of heating energy per day. Our goal was to meet 100% of demand year-round with solar hot water. We used NREL’s PVWatts calculator to determine the solar energy available at our location. Then, using efficiency data from the Solar Rating & Certification Corporation, we determined the system components and size (see Access). For simplicity and to avoid the need for a heat-dump loop for overproduction in the summer, we chose an unpressurized drainback system using three Sun Earth EC-40, 4- by 10-foot, flat-plate selective-coating collectors and a 120-gallon storage tank with dual heat exchangers and an electric resistance backup heater.

the U-factor becomes more critical than SHGC to reduce heat load. This will vary from design to design and with specific climate as the solar heat contribution is offset by thermal losses through the windows at night and on cloudy days.

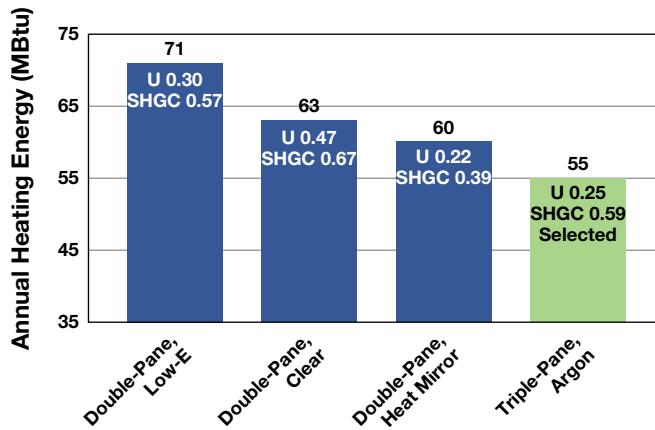
We ultimately settled on argon-gas-filled, triple-pane windows with a high-gain, low-e coating, customized for the south face to be made with low-iron glass, which raised the center-of-glass SHGC by 11%. Although it was hard to justify these expensive windows, we decided to put money into the higher-performing windows simply for the energy savings. We also plan to enhance these windows with quilted, insulated window shades.

### Energy Design Meets Reality: Balancing Efficiency with Economy

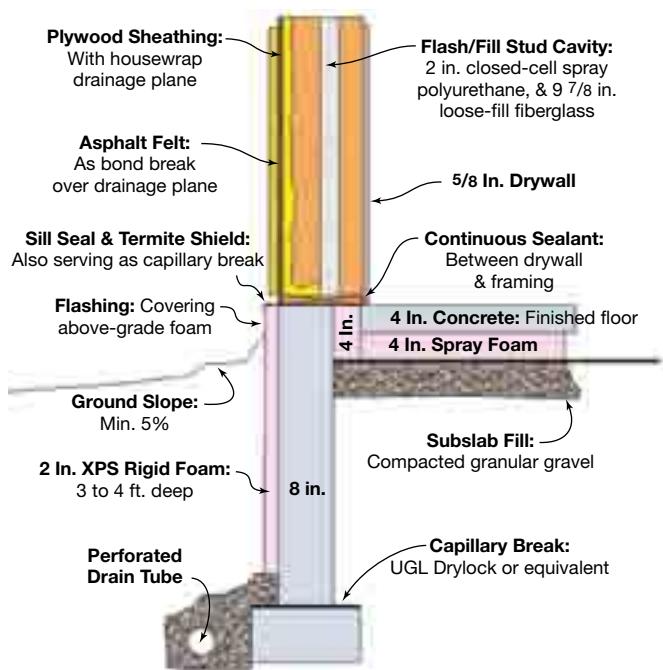
With the design concept complete, we hired local designer David Woody to meld our energy design into the Sun Plans design—and to make sure the home would meet local building codes. Our builder, Doug Strecker of Rampart Custom Homes, was anxious to tackle a net-zero energy home and provided a dose of local labor and materials cost reality.

**Slab.** A 4-inch-thick slab-on-grade, with R-20 closed-cell polyurethane spray foam insulation under the slab and on the outside of the stem-wall. This will thermally isolate the slab from the foundation wall and ground, and significantly reduces conduction loss through the floor into the relatively cool earth and foundation.

## Window Type



## Foundation Construction

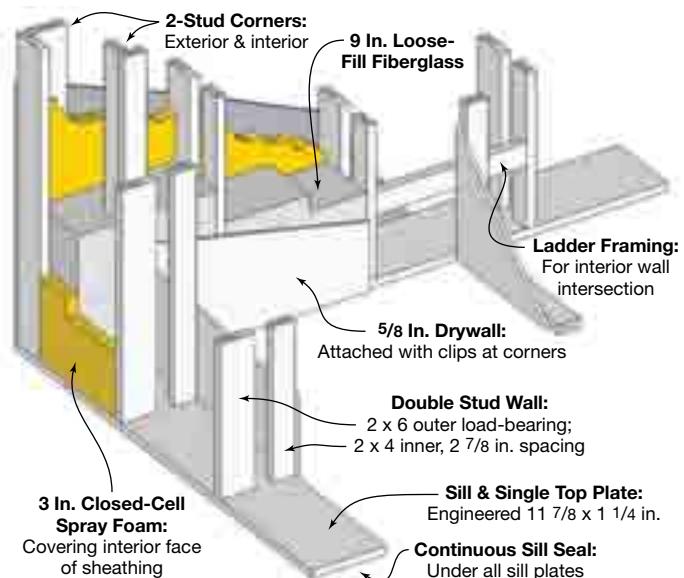


**Walls.** Using 6-inch-thick polyurethane SIPs exceeded our budget. Switching to 2-by-6 walls, insulated with blown fiberglass in the stud cavities and 4 inches of exterior rigid (polyisocyanurate) foam on the exterior, would yield comparable performance. This was still a more expensive option (labor and materials combined) than the one we ultimately selected: double stud wall construction. Overall, SIP exterior wall construction ran 14% higher than the double-wall, and the 2-by-6 with exterior foam ran 5% higher. The economic argument will vary widely from city to city depending on local labor and material costs. The double-wall technique uses more lumber but goes up more quickly than a single wall with two layers of exterior foam plus more intricate sealing and trim work around the windows.

The double stud wall is constructed of 2-by-6 and 2-by-4 studs. Three inches space between the inner and outer studs provides a thermal break, resulting in a high-thermal performance wall. Three inches of closed cell spray foam along the outer sheathing and 9 inches of blown-in fiberglass yields R-49. Stud spacing at 24 inches on center, using "advanced framing" techniques, results in a more efficient use of lumber.

**Roof.** The roof was designed with a 40° pitch on the south side to be optimally oriented for a PV array. The north roof was sloped at 26° to reduce surface area heat loss. Parallel truss construction gave an open attic and mechanical space. With 3 inches of closed-cell spray foam and 15 inches of blown cellulose, the roof was insulated to R-66. A standing-seam metal "cool roof" helps reflect sunlight, helping to reduce the cooling load in the summer. As with the wall construction, the labor and materials costs were less than a SIP roof or 2-by-10 rafters with 4 inches of exterior foam on the roof deck.

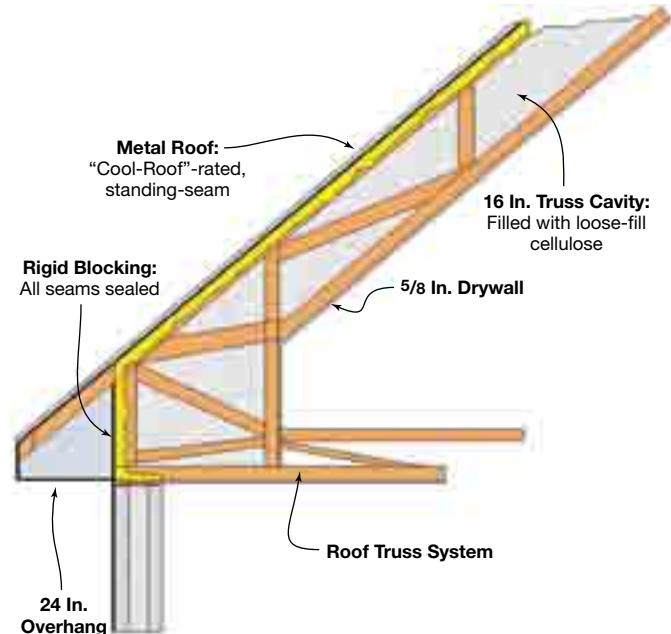
## Wall Construction, R-49



**Windows.** The selected windows are triple-pane, foam-filled fiberglass from Accurate Dorwin Company of Winnipeg, Canada. Operable windows will be casement or awning types, which seal better than sliding or hung windows. South-facing windows will have a SHGC = 0.59 and a U-factor = 0.25; and north facing will have SHGC = 0.27 and U-factor = 0.16

Our passive solar design included no glazing on east or west faces, with limited glazing on the north side for daylighting. The south-facing glazing is about 8.5% of total floor area, well within established passive solar design recommendations.

## Roof Construction, R-66



**Air Sealing & Ventilation.** The house's airtight design is aided by the barrier layer of spray foam inside the entire shell. The use of a condensing, non-vented clothes dryer and a recirculating range hood also helps keep the thermal boundary tight and eliminate pressure imbalances.

We chose the Ultimateair RecoupAerator whole-house energy recovery ventilator (ERV) with a high recovery efficiency (see Access). The ERV intake air will run through a 100-foot-long earth tube and a water-to-air heat exchanger using solar hot water for preheating.

### Specific Design Modeling Results

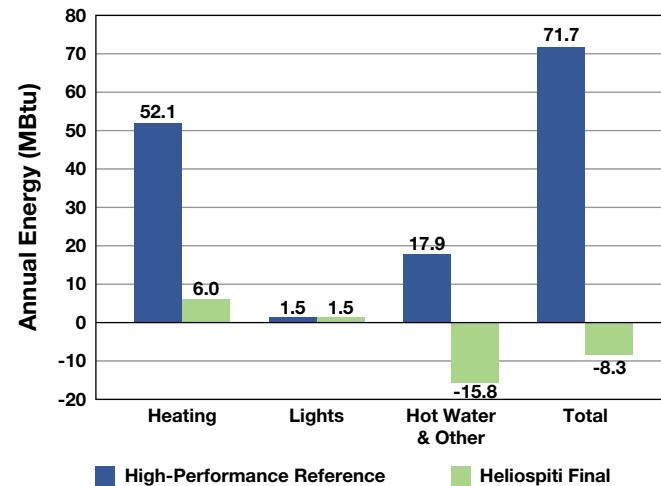
With the overall design complete and windows specified, we re-modeled the house in Energy-10 to determine what backup heating system would be best. We had maximized the passive efficiency and solar gain of the building envelope within our budget. Now, in keeping with the *passivhaus* philosophy, we sought the smallest, most cost-effective backup mechanical heating system to satisfy the remaining heating load.

For our Heliospiti project, Energy-10 indicated an 18 kBtu per hour peak heating load without solar gains, and 4.5 kBtu per hour with passive solar gains included. We selected a mini-split air-source heat pump that the manufacturer claims should provide 100% heating capacity to 5°F and reduced heating, without electric resistance backup, down to -13°F. This unit has a maximum capacity of 10.9 kBtu per hour at 5°F. Only real-world experience will reveal if the mini-split heat pump performs up to the manufacturer's specifications and the passive solar design offers the heating predicted by the modeling software.

In Energy-10, the model reports heating and cooling energy consumption regardless of the energy source. On-site generation only shows up in the "Other" category as negative electrical consumption, and negative water heating energy. "Lighting" doesn't change for the same reason.

The predicted energy use modeled for our home is a net annual production of 8,335 kBtu (a result of the PV and SHW systems)—meeting our goal of true net-zero energy in an all-electric house. The graph compares our design to a high-performance reference home following Energy Star criteria with R-5 slab insulation, R-38 ceiling, 2-by-6 R-17 walls, and Energy Star-rated windows. Heliospiti's active solar systems aren't factored into the heating equation—the Energy-10

### Final Energy Comparison



comparison just reflects the effects of insulation, air sealing and passive solar design (passive thermal losses and passive solar gain) with the reference house.

And now we look forward with anticipation as we watch the house go up—waiting to see how closely Heliospiti meets the modeling predictions.

### Access

Jim Riggins (info@enersmartenergy.com) is the principal of EnerSmart Energy Solutions ([www.enersmartenergy.com](http://www.enersmartenergy.com)) and a Residential Energy Services Network (RESNET) certified home energy rater. He and his wife Elise plan to use Heliospiti as a showcase of affordable, energy-efficient construction.

Built Green checklist • [www.builtgreen.org](http://www.builtgreen.org)

Cool Roof Rating Council • [www.coolroofs.org](http://www.coolroofs.org)

Green Building Guidelines • [www1.eere.energy.gov/buildings/building\\_america](http://www1.eere.energy.gov/buildings/building_america)

Home Ventilating Institute product comparisons • [www.hvi.org](http://www.hvi.org)

National Fenestration Rating Council • [www.nfrc.org](http://www.nfrc.org)

PVWatts Solar Calculator • [www.nrel.gov/rredc/pvwatts](http://www.nrel.gov/rredc/pvwatts)

National Weather Service • [www.nws.noaa.gov](http://www.nws.noaa.gov)

Solar Rating & Certification Corporation • [www.solar-rating.org](http://www.solar-rating.org)

Sun Plans • [www.sunplans.com](http://www.sunplans.com)

Sustainable By Design • [www.susdesign.com](http://www.susdesign.com)

U.S. DOE/EERE's Building Energy Software Tools Directory • [http://apps1.eere.energy.gov/buildings/tools\\_directory](http://apps1.eere.energy.gov/buildings/tools_directory)

U.S. EPA WaterSense Guidelines • [www.epa.gov/WaterSense](http://www.epa.gov/WaterSense)

## Energy-10 Modeling Results

	Annual Energy Consumption (kBtu)	
	Without PV & SHW	With PV & SHW
Heating	5,954	5,954*
Cooling	0	0
Lighting	1,489	1,489
Other electric loads	19,946	-15,778**
<b>Total Annual Energy Use</b>	<b>27,389</b>	<b>-8,335*</b>

\*SHW is used for domestic water heating only; none goes to space heating

\*\*Negative numbers reflect the sum of all on-site production, both PV and SHW



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# BATTERY BOX

## *design*

**Story & photos by Allan Sindelar**

Batteries are a necessary, albeit expensive, component in off-grid RE systems—so you'll want to give them good care. Good battery enclosure design and construction will protect you, your family, and your property from potential battery mishaps, and can enhance the effectiveness of the battery bank as well. Battery enclosures serve four main functions:

- Provide physical protection to the batteries from tools, falls, dust, debris, etc.
- Isolate and safely vent hydrogen gas to the outdoors.
- Maintain a consistent temperature among the cells.
- Meet the requirements of the *National Electrical Code*, Articles 480 and 690 (Section 690.71), see sidebar.

**Physical Protection.** Batteries store electrical energy using a chemical reaction, and can present acid burn, electrical burns, or explosion hazards if they are improperly handled or contained. When it comes to housing your batteries, your goal should be to provide a clean, dry, ventilated, semiconditioned space that prevents unqualified people from coming into contact with the battery bank.

Although we have seen a variety of materials used successfully—plastic storage totes and coolers, fiberglass-reinforced plastic, sheet PVC, and even old refrigerators—plywood works fairly well for residential boxes. It's familiar, attractive, versatile, dimensionally stable, and strong. Most owner-builders and building crews can make a good box, and it is adaptable to specific sites and needs. The wood will quickly decay, however, if it comes in contact with battery electrolyte. Plywood should be  $\frac{1}{2}$ -inch thick at minimum; better is  $\frac{3}{4}$ -inch, or a combination of  $\frac{3}{4}$ - and  $\frac{1}{2}$ -inch panels. The box may be called on to support a ton or more of batteries. "A-C" or "B-C" grade or better is recommended. ("A" is the highest grade. The first letter indicates the quality of the face veneer; the second letter, the back veneer.) The best plywood material we have used is called "Baltic Birch," available through wholesale lumber and hardwood suppliers. It is  $\frac{1}{2}$ -inch thick with nine plies, and comes in various sheet sizes, including our preferred 60- by 60-inch. Besides being attractive, it is dimensionally stable and easy to work with.

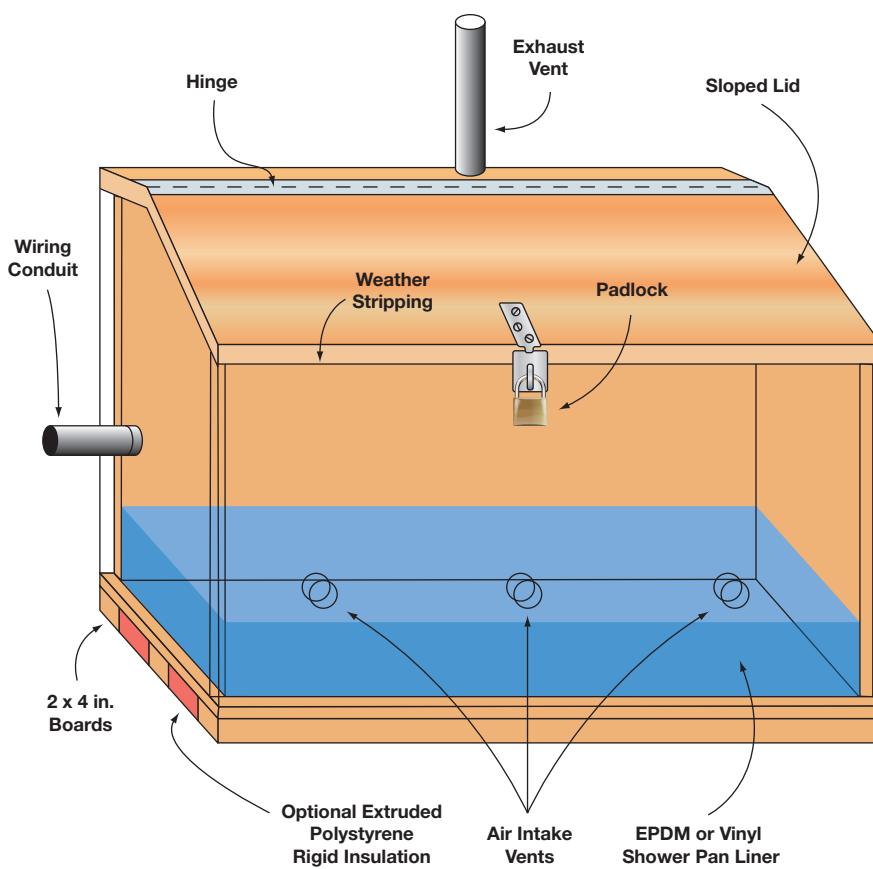
A battery box should typically not be deeper front to back than about 24 inches or maintenance becomes difficult on the rear rows. This is about the depth of three rows of L16s or

two rows of larger industrial-type cells. The length of the box often ends up between 48 and 60 inches. For example, a row of four L16s is about 50 inches. If space is factored in between each battery for ventilation, this translates into a box length of about 60 inches. Two or three sheets of 60-inch plywood is enough for most battery enclosures, with little of the waste if the panels had been cut from conventional 4-by-8-foot plywood.

**There are many configurations for battery boxes. This large box is double-sided, with power vents and transparent lids for easy viewing.**



## Battery Box Construction Details



### Battery Box Checklist

- ✓ Vent hydrogen gas to the outdoors
- ✓ Line battery box to contain battery acid spillage
- ✓ Place air intake vents low, but above liner
- ✓ Use duct seal around the battery cables where it enters the conduit to keep gas out of the conduit
- ✓ Caulk the battery box and seal cover with weather stripping
- ✓ Plywood: 1/2- to 3/4-inch thickness; A-C or B-C grade or better
- ✓ Insulate bottom of box if floors stay cold all winter
- ✓ Restrict access to batteries, such as with a latch and/or padlock
- ✓ Keep battery box depth at 24 inches or less to reach and maintain back batteries
- ✓ Leave room for battery posts, cables, interconnects, and handles, and maneuvering a water jug

Even if a box can be less than 48 inches long, a larger enclosure may be justified. A small system that uses golf-cart batteries may some day be upgraded to L16s or industrial 2 V cells. A golf-cart battery is about  $10\frac{1}{2}$  inches long; an L16 is about  $12\frac{1}{4}$  inches. So upsizing the box initially to fit future battery possibilities may save money in the long run.

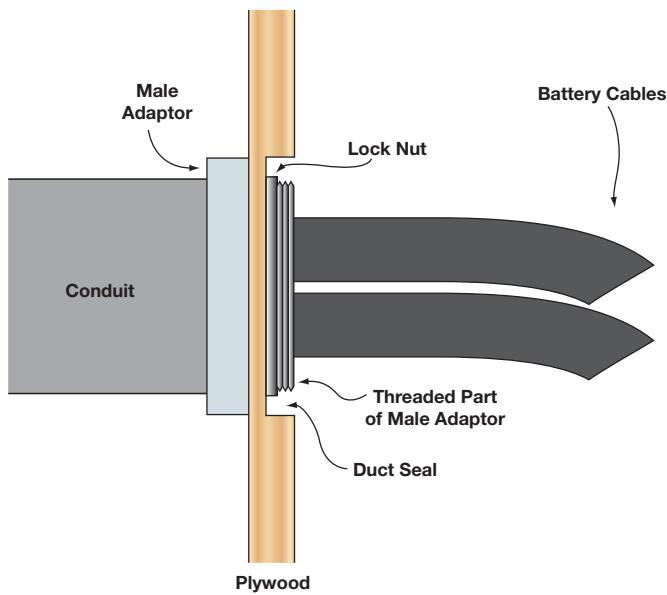
To plan a successful battery box layout, draw out the batteries on paper, or make cardboard templates. Leave room around battery cases for ventilation, to hide rope handles, to maneuver a distilled water jug, and to get fingers and tools into the box for service. Leave 3 to 6 inches above the battery tops for cables and interconnects. Plan the placement and lengths of your interconnects so that all fill caps are readily accessible and battery cables do not lay over the cell tops.

The inside of the box should be carefully caulked, and painted or treated with a penetrating sealer to resist minor spills or corrosive vapors. For best results, a liner of 40-mil EPDM rubber or pond liner (available at many nurseries or home improvement stores) is placed in the bottom and about 6-8 inches up the sides, folding instead of cutting for the corners. This liner protects the wood and forms a leakproof

**Well-constructed battery enclosures are an important part of the balance of the system equipment, and should not be ignored.**



## Securing Battery-to-Inverter Conduit



container to contain any accidental spills or leakage from the cases. Above this level, typically three 1- or  $1\frac{1}{4}$ -inch inlet ventilation holes are drilled across the front. The outside of the box should be finished with primer and paint if exposed to the weather, or varnish or penetrating oil, if inside. A removable box front can make replacing batteries easier, but

this is generally only necessary with heavy industrial cells (which may tip the scales at more than 150 pounds each).

The cover should be hinged at the top to seal securely, yet allow access to the batteries for service. A piano hinge works well, as it prevents warping and is easy to seal. The lid should be sloped, partly to guide vapors up toward the vent, but mostly to discourage storing things on the box and resultant neglecting of normal maintenance. A flat-top panel about 4 inches wide behind the piano hinge will accommodate the vent pipe. The cover should be sealed with weather-stripping—soft neoprene works well; foam won't last. A kerf cut into an inside trim strip allows modern replaceable door weather-stripping to be used. Silicone rubber "flipper seals" are ideal because they are effective over a wide range of gaps and require little closing pressure (see Access). The cover should have latches. Even hooks and eyes, especially if adjustable, make a good basic latch. Use a lock, like a padlock and hasp, to prevent access to the battery by unqualified people.

A well-designed box will have a base similar to a kitchen cabinet to allow for a toe-kick space and to raise the batteries for ease of maintenance. If the bank sits on a cold slab, the box's floor can be built on 2-by-4 sleepers with rigid foam fit between or above them, keeping your battery bank warmer. Extruded polystyrene insulation panels will support battery weight.

For cable entry into the box, some installers place the conduit hole lower in the box, below the battery tops, since the hydrogen gas rises, and would be less likely to go into the conduit. Electrical conduit fittings are designed to attach to junction boxes made of thin sheet metal, not thicker plywood.

**A peek inside this battery enclosure shows a clean installation, with ample room for the battery cases and interconnects.**

**Battery boxes aren't always made from plywood. This example is fabricated from stainless steel.**



To secure battery conduit fittings to the battery box, we use two concentric hole saws from opposite sides, creating a 1/4-inch-thick flange to fit a lock ring around 1 1/2-inch (for 2/0 cables) or 2-inch (for 4/0 cables) battery conduit. This allows the threads of the conduit fitting to get into the box

## Before You Build, Check the Code

*National Electrical Code (NEC)* Article 480 and Section 690.71 address battery installation and containment, and should be referred to prior to designing or building your battery enclosure. In most instances, residential battery systems are limited to 50 VDC nominal. (Requirements for battery packs operating at greater than 50 VDC nominal are not addressed in this article.)

Regardless of battery type (sealed or flooded), adequate ventilation is required to “prevent the accumulation of an explosive mixture.” While ventilation specifics are not clearly outlined in the NEC, some important considerations are identified. In the *NEC Handbook*, an explanation is given for Section 480.9 (A), stating that “hydrogen disperses rapidly and requires little air movement to prevent accumulation. Unrestricted natural air movement in the vicinity of the battery, together with normal air changes for occupied spaces or heat removal, normally is sufficient. If the space is confined, mechanical ventilation may be required in the vicinity of the battery.”

Because hydrogen is lighter than air and will tend to concentrate at ceiling level, the *NEC Handbook* states that “some form of ventilation should be provided at the upper portion of the structure. Ventilation can be a fan, roof ridge vent, or louvered area.” A common approach used to meet these requirements, especially when flooded batteries are used, is the inclusion of one or more air intake vents installed low on the battery enclosure, used in conjunction with a pipe-connected exhaust vent that routes gases to the outdoors.

All live parts of battery systems, including terminals and cable lugs, are required to be guarded, or covered, to protect against the possibility of an electrical short if a tool or other metal object is inadvertently dropped across the batteries. In addition, access to the battery bank should be limited, either by locking the battery room or enclosure, or restricting access with some other permanent means (Article 110.27).

The battery enclosure cover or doors should allow adequate and convenient access to the battery bank for qualified people, and adequate working clearances should be provided (Article 110.26).

Finally, the *NEC Handbook* includes the following reference to flooded versus sealed batteries: “Although valve-regulated batteries are often referred to as ‘sealed,’ they actually emit very small quantities of hydrogen gas under normal operation, and are capable of liberating large quantities of explosive gases if overcharged. These batteries therefore require the same amount of ventilation as their vented counterparts” (Article 480.9).



This battery box, with a removable front, makes future battery replacement easier.

with enough room for the lock nut to be attached. Then we use “duct seal,” available at electrical supply houses, to carefully seal this fitting around the cables to keep gases away from the electrical equipment.

**Safe Venting.** Hydrogen is explosive if allowed to collect to a concentration exceeding about 4%. The gas mixture given off during charging also contains minute amounts of sulfuric acid, which is corrosive to electronics and most metals. As such, a well-built battery box is both sealed and vented, so that the gas may be carried to the outdoors to dissipate. Fortunately, hydrogen is Earth’s lightest element, so it easily rises in air. A vent pipe at the top of the box will work. A second low vent allows ventilation air to enter the box.

The vent is typically made of 2-inch PVC water pipe or the equivalent. Larger sizes of PVC pipe may be used, but excessive venting can let too much heat escape in winter. The exhaust vent should exit through the building wall or roof, with all laterals rising. An insect screen should cover the outside end, with protection from rain and snow entry.

Zephyr Industries’ Power Vent can be installed in a vertical section of the PVC stack, and works well for smaller venting demands. When the battery voltage rises to a setpoint below the gassing voltage, the vent’s DC fan is activated. A backdraft damper prevents reverse airflow into the room. Many modern charge controllers and some inverters can automatically control Power Vent operation by one of their auxiliary relays; some even have “vent fan” as a programmable option.

**Keeping Temperatures Constant.** Insulating a battery box seldom makes much difference if the insulated box is located



This battery enclosure allows for stacking batteries, reducing the footprint required. This is one clear benefit of sealed batteries, as access to cell caps to add water is unnecessary.

in a cold environment. Insulation slows the rate of heat loss from a warm space or object to a cooler space. Batteries are not a significant heat source; the normal charge/discharge process produces a negligible amount of usable heat. No amount of insulation will prevent batteries from eventually reaching the temperature of the environment around the insulated box, so while insulation may be included, it's important to locate the box in a tempered space. Batteries like to live at about the same temperatures humans enjoy. For optimal battery performance and longevity, select a location and enclosure design that will keep your batteries between 50°F and 75°F.

## Access

Allan Sindelar (allan@positiveenergysolar.com) installed his first off-grid PV system in 1988, founded Positive Energy in Santa Fe, New Mexico, in 1997, and has lived off-grid since 1999. He is a licensed commercial electrician and a NABCEP-certified PV installer.

## Resources:

Conservation Technology • [www.conservationtechnology.com/building\\_weatherseals.html](http://www.conservationtechnology.com/building_weatherseals.html) • Silicone weather stripping

Zephyr Industries • [www.zephyrvent.com](http://www.zephyrvent.com) • Power Vent



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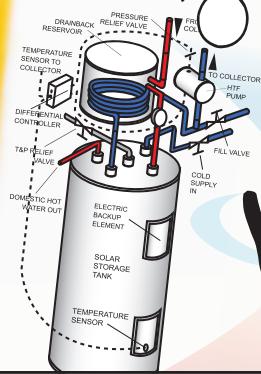
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Rolf Meissner, PhD, "The Key for Optimizing Large-Scale Solar Thermal Systems", Linuo Paradigma Solar Energy, 2009

for data & discussion, please see

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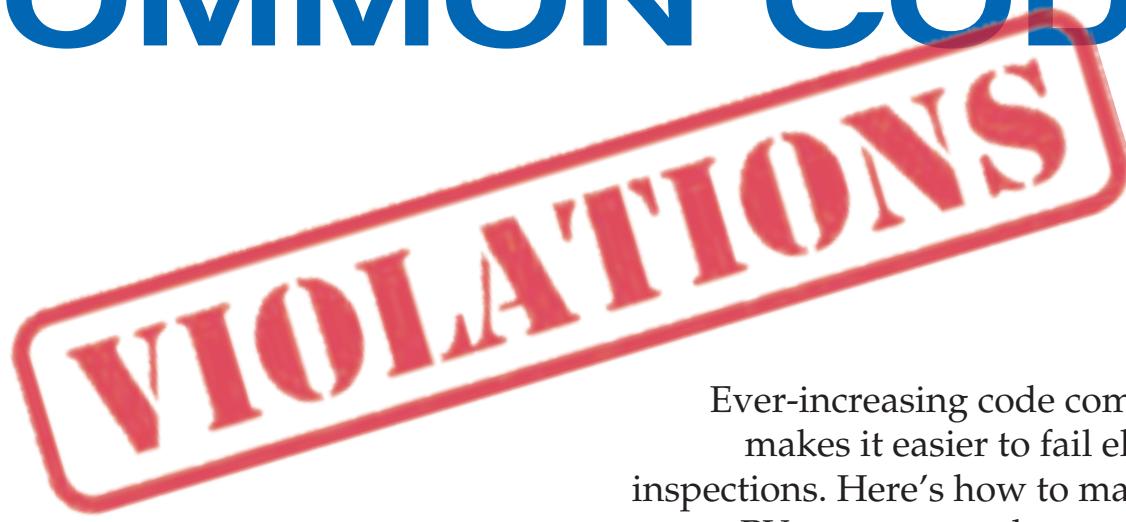


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# Residential PV Systems COMMON CODE



Ever-increasing code complexity makes it easier to fail electrical inspections. Here's how to make sure your PV system gets the green light.

by Ryan Mayfield

The first residential PV projects—remote, off-grid systems—were installed far from the long arm of building inspectors. As a consequence, many early PV installers were not familiar with and did not follow the standards set by the *National Electrical Code* (NEC), the *International Building Code* (IBC), and local jurisdictions.

But that's changed. Multitudes of mainstream systems installed on residential roofs have focused attention on safety requirements, often calling for multiple permits and inspections. Installation techniques and practices have evolved accordingly.

Complicating residential PV installation is the introduction of new equipment and methods. To keep up with changing products, governing codes are being updated. This requires contractors to stay abreast of new information and requirements as they are released. Many new—and sometimes old—code compliance issues surface during PV system installation and inspection. Additionally, depending on your jurisdiction, you may be held to current code cycles or previous versions. This can lead to confusion among contractors, PV installers, and enforcement and inspection officials, especially as they communicate with peers in other states and jurisdictions.

## Common Code Violations

The NEC is the guiding document for the electrical portion of PV installations. Some jurisdictions have additional or different requirements, but most are based on the *NEC*. While the *NEC* is considered the premier document guiding electrical installations, its acceptance and interpretation is determined by the authority having jurisdiction (AHJ, or electrical inspector), as outlined in Section 90.4.

**Sloppy work.** NEC Section 110.12 states that "Electrical equipment shall be installed in a neat and workmanlike manner." While the *Code* does not have specific guidelines to illustrate this requirement, and inspectors will have a hard time defining it, they will know it when they see it. When work is done poorly, it is a cue to inspectors to look even harder for additional *Code* violations. The *National Electrical Installation Standard—Standard for Good Workmanship in Electrical Contracting* published by the National Electrical Contractors Association defines this requirement (see Access).

Wire management is one critical issue to consider during installation. Since most PV modules come with factory-installed quick-connect plugs, using conduit to protect and manage the array wiring can be challenging. Plus, wiring must be properly supported to prevent it from damage, especially where it could be exposed to mechanical wear and tear.

**Not installed to listing.** Section 110.3(B) says that listed or labeled equipment must be used for its intended purpose. A common electrical mistake is to install an overcurrent protection device (OCPD), such as a circuit breaker or fuse that has the incorrect amperage rating, thereby violating the inverter manufacturer's listing. This can inadequately protect the conductors or result in nuisance tripping, which ultimately reduces energy production.

Improperly sized fuses or circuit breakers for PV source circuits present another issue. All PV modules come with a series fuse rating to determine the maximum PV source circuits' overcurrent protection. The minimum OCPD used to protect PV power circuits needs to be sized based on *NEC* Section 690.8—not based on what is on the truck that day (see *Code Corner* in this issue).

Most of a PV system's components will be installed in an outdoor location, necessitating their listing for outdoor use and exposure to the elements. Many of the enclosures used will carry a National Electrical Manufacturers Association (NEMA) rating of at least 3R—an enclosure with this rating is weather-resistant when mounted vertically.

Most NEMA 3R boxes are not considered weather-resistant when mounted at any other angle, so using a NEMA 3R junction box or disconnect mounted parallel to a roof surface is a direct violation of the *Code*. It is possible to use a NEMA 4 enclosure where the location requires mounting the box on an incline or even on its back. Several combiner box manufacturers use NEMA 4 enclosures, but most disconnects must be mounted on a vertical surface.

Section 690.4(D), an addition in the 2008 *NEC*, requires that equipment used in PV systems, including source-circuit combiner boxes, "shall be identified and listed for the application." This restricts using on-site-manufactured combiner boxes. PV combiner boxes need to be listed to Underwriters Laboratories' (UL) Standard 1741. Installers can choose from among several types of combiner boxes, from simple junction boxes to large multiple string combiners, that incorporate fusing or breakers.

## Wiring Methods

PV systems present their own set of wiring challenges. Source-circuit wiring is often exposed to sunlight and extreme temperatures, while output circuits are often run at very high DC voltages inside potentially hot conduit. The inverter output circuit for grid-tied inverters sends electricity into the grid—in the minds of many inspectors, the wrong direction for current to flow. Live DC circuits on the roof always cause inspectors grave concern, even though these are inherently current-limited. These are all legitimate concerns that system designers and installers need to account for and be prepared to explain to permit and inspection officials.

**Temperature correction.** One of the first *Code* requirements that PV installers need to review is Article 110, which

**Conductors need to be properly supported and protected from damage to ensure system longevity, performance and safety.**  
This photo shows a myriad code violations.



**NEMA 3R-rated boxes should not be installed at angles less than 14 degrees.**

addresses general requirements for electrical installations, including working clearances, equipment mounting, and temperature limitations associated with conductor ampacity. Since PV systems can be exposed to high temperatures, this section can have major implications.

Article 310 of the 2008 *NEC* (and 2011 *NEC*) includes Table 310.15(B)(2)(c), "Ambient Temperature Adjustment for Conduits Exposed to Sunlight On or Above Rooftops." The adjustments in this table "shall be added to the outdoor temperature to determine the applicable ambient temperature for application of the correction factors in Table 310.16 and Table 310.18." This adjustment can require significantly larger wire sizes, depending on the local temperatures and the height of the conduit off the roof. This is one of the areas that catches some traditional electricians, since many of them do not estimate rooftop temperatures accurately.

Equipment must be compatible with the temperatures it will experience, including properly rated conduit, wiring, and enclosures. Installers also need to be aware of temperature effects on conduit expansion and contraction, and must be installed on roofs with expansion couplings and proper support.

Section 310.15(A)(2) includes an exception allowing for a less restrictive calculation for short rooftop conduit runs (10 feet or less than 10% of the total circuit length, whichever is less). If the conduit is minimally exposed, the balance of the conduit length is able to dissipate the heat effectively, thereby reducing the heating impact. This exception may allow installers of residential PV to avoid upsizing conductors and conduit.

**Color-coding.** A longstanding convention in PV installations is to mark the positive DC circuit conductor red and the negative conductor black. While this may be recognizable to PV professionals, it is not a correct method per the *NEC*, nor is it safe, since it may lead to confusion among other tradespeople.

“A longstanding convention in PV installations is to mark the positive DC circuit conductor red and the negative conductor black. While this may be recognizable to PV professionals, it is not a correct method per the *NEC*, nor is it safe, since it may lead to confusion among other tradespeople.”

Section 200.6(A) dictates that grounded current-carrying conductors smaller than 6 AWG “shall be identified by a continuous white or gray outer finish or by three continuous white stripes on other than green insulation along its entire length.” An exception to 200.6(A)(2) allows PV source conductors to be installed and marked at their terminations. The use of white tape on black wire, for example, can identify a PV source conductor as grounded.

When describing and calling out conductors, it is more appropriate to refer to *nongrounded current-carrying conductors* and *grounded current-carrying conductors*. The former is typically the positive conductor, and the latter typically the negative. This is more descriptive and identifies the conductor’s role in the circuit to qualified personnel. Under this nomenclature, color coding is also clarified.

The nongrounded current-carrying conductor may be any color other than white, gray, green, or green with yellow stripes. Typically, this conductor is red, which is acceptable per the *NEC* and stands out to a technician servicing the system. When a positively grounded PV system is employed, it may be in the installer’s best interest to use both proper color coding (such as having a white positive conductor and black or red negative conductors) and additional labeling to identify the system as positively grounded.

**Not only are these conductors not rated for the environment in which they are installed, but they are also exposed to potential physical damage from the hardware edges.**



Courtesy www.mmslledu/~tdi

**Readily accessible conductors.** *NEC* Section 690.31(B) allows for the installation of unprotected current-carrying conductors in PV systems. In the 2008 and 2011 *NEC*, however, 690.31(A) states, “Where photovoltaic source and output circuits operating at maximum system voltages greater than 30 volts are installed in readily accessible locations, circuit conductors shall be installed in a raceway.”

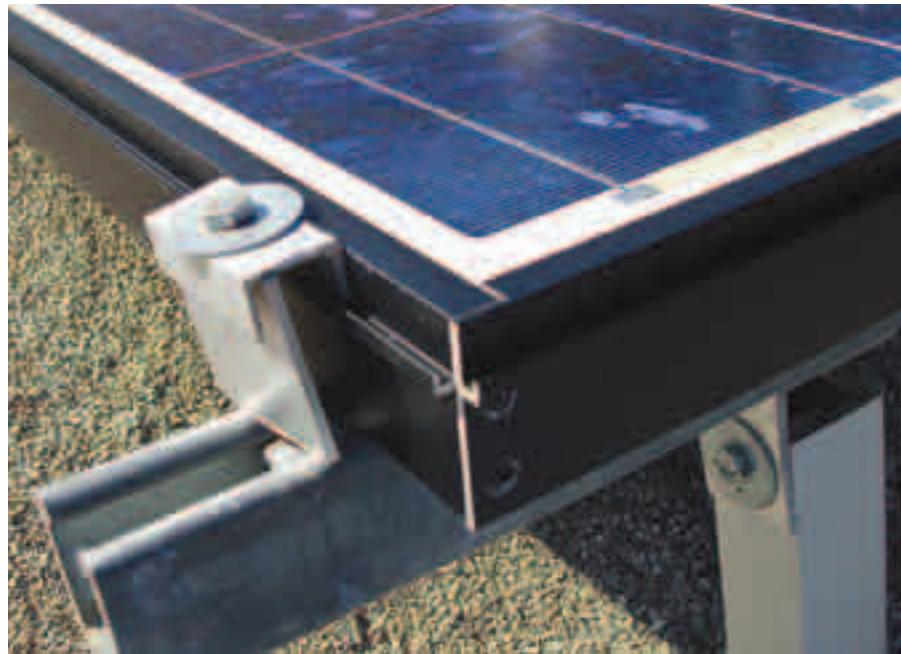
This requirement is problematic for ground-mounted or other PV arrays that are considered “readily accessible” per *NEC* Article 100, and those that use modules with quick-connect cables attached to the junction boxes, since these modules don’t have a method for conduit attachment, making article compliance difficult to achieve. The installer is left with the dilemma of how to best install the system *and* comply with the *NEC*. For ground-mounted systems, an easy answer is to build a fence to keep the system isolated. Another method to render the wiring inaccessible is to create a wiring chase that integrates with the racking system. Work closely with the AHJ to determine what is acceptable.

Section 690.31(E), which first appeared in the 2005 *NEC*, allows DC conductors from the PV array to run through a structure before being terminated at a readily accessible disconnect, as long as the conductors are located in a metallic raceway. The 2008 *NEC* generally accepted that *metallic raceways* include conduit such as EMT and flexible metallic conduit, but not metal-clad cable, which is technically a cable assembly. The section also includes language that refers specifically to grid-tied inverters; depending on your AHJ’s interpretation, the method outlined in Section 690.31(E) may not be acceptable for off-grid installations. For systems installed based on the 2011 *NEC*, see the 2011 *NEC* Section 690.31(E) sidebar for an outline of the new requirements.

**Point of connection.** One of the requirements in the 2008 and 2011 *NEC* makes a violation out of a common practice allowed in the 2005 *Code*. Section 690.64(B)—or Section 705.12(D) in the 2011 *NEC*—now requires that the inverter output connection for grid-tied systems be made at the *opposite end* of the bus bar from the main circuit breaker location, unless the sum of these two breakers is less than the bus bar rating. Per this language, in typical residential installations, the inverter connection must be located at the opposite end of the panel from the main breaker, with the PV breaker labeled, “Do not relocate.”

**Fine-stranded cables.** Section 690.31(F), added in the 2008 *NEC*, specifically requires that fine-stranded cables only be used with terminals or lugs identified and listed for

This homemade mounting system appears to put dissimilar metals in direct contact with one another. Sloppy mechanical work is often an invitation to inspectors to look even harder for other *Code* violations.



such use. In battery-based systems, it is common to use fine-stranded cables for the battery interconnects and the battery-to-inverter connection.

When fine-stranded cables are used in connections not specifically listed for that use, the conductors will expand and contract within the connection, eventually causing a high-resistance connection and, possibly, leading to failure.

## Labeling

**Required labels.** Article 690 lists numerous requirements for labeling equipment, with more requirements added each *Code* cycle. For proper signage, installers must refer specifically to Sections 690.17, 690.31(E)—see 2011 *NEC* Section 690.31(E) sidebar—690.35, 690.53, 690.54 and 690.64 (705.12 in the 2011 *NEC*). Labeling the equipment is an extremely important, yet commonly overlooked, requirement in PV installations. It is one of the final steps in an installation, but the labeling requirements should be identified before the first module is placed.

“Direct-Current Photovoltaic Power Source,” one of the labels required in *NEC* 690.53, calls for a permanent label for the DC disconnecting means that specifies the PV maximum system voltage, short-circuit current, and the rated maximum power point voltage and current.

The following example calculations for a typical residential system illustrate how to obtain the values for labels:

- PV array capacity: 5,390 W STC; 22 SolarWorld 245 W modules
- Module specifications: SolarWorld Sunmodule SW245; 37.7 Voc, 30.8 Vmp, 8.25 Isc, 7.96 Imp, -0.124 V/°C Voc temperature coefficient
- Array configuration: 11 modules per series string with two strings paralleled in a roof-mounted combiner
- Record-low site temperature: -10°C
- Inverter: PV Powered PVP4800, 4.8 kW, 500 VDC maximum input, 200–450 VDC MPPT range

The rated maximum power point voltage and current values are rather straightforward—they are determined by the module manufacturer’s specifications at STC. The 2005 *Code* requires listing the operating current and voltage, and the 2008 *Code* helps clarify that language.

$$\text{Imp} = \text{Module Imp} \times \text{strings in parallel}$$

$$7.96 \text{ A} \times 2 = 15.92 \text{ A}$$

$$\text{Vmp} = \text{Module Vmp} \times \text{number of modules per string}$$

$$30.8 \text{ V} \times 11 = 338.8 \text{ V}$$

Section 690.53(3) in the 2008 *Code* contains a fine-print note (FPN) that instructs listing the maximum voltage as calculated in Section 690.7. Depending on the *Code* version you are working with, this value may be the array’s open circuit voltage at STC multiplied by the correction factor listed in 690.7, or it may be calculated from module manufacturer data.

$$\text{Max Voc} = \{37.7 \text{ V} + [(T_{\min} - T_{\text{STC}}) \times \text{coeff}]\} \times 11$$

$$\{37.7 \text{ V} + [(-10^{\circ}\text{C} - 25^{\circ}\text{C}) \times -0.124 \text{ V/}^{\circ}\text{C}]\} \times 11 = 462.4 \text{ V}$$

The fourth piece of information required is the array’s short-circuit current. Again, the 2008 *NEC* has added an FPN to clarify this calculation that references Article 690.8(A), which requires multiplying the array’s short-circuit current by 1.25 to determine the value to list on the label.

$$\text{Isc} = \text{Module Isc rating} \times \text{strings in parallel} \times 1.25$$

$$8.25 \text{ A} \times 2 \times 1.25 = 20.63 \text{ A}$$

Rounding to the nearest whole numbers, the label applied at this site should read:

**DC PV POWER SOURCE**  
**Imp: 16 A**  
**Vmp: 339 V**  
**Max Voc: 462 V**  
**Isc: 21 A**



Shawn Schreiner

To comply with the *NEC*, a system's electrical parameters need to be clearly labeled, as shown here.

Also required is a listing for the "maximum rated output current of the charge controller (if installed)." Where applicable, this value is can be found in the charge controller manufacturer's specifications.

Articles 690 and 705 require additional labels, such as the one required in Section 690.56(B), which specifies "a permanent plaque or directory providing the location of the service disconnecting means and the photovoltaic system disconnecting means, if not located at the same location." This isn't so much a label as it is a map. Two directory labels may be needed to identify the locations of the disconnecting means for both the PV system and the service.

**Label material and attachment.** The 2008 and 2011 *NEC* require permanent labels—many installers use plastic or metal engraved signs. When plastic is used, it should not be placed in direct sunlight, unless the plastic is specifically manufactured as sunlight-resistant. Where a label is installed in direct sunlight, a metallic engraved sign is generally more appropriate.

The most accepted practice is to install labels with an adhesive that is rated for outdoor locations and high temperatures. These labels generally meet *Code* requirements and are often acceptable for residential applications, depending on the AHJ's *Code* interpretations.

## 2011 *NEC* Section 690.31(E)

The new version of this section allows running PV source or output circuits (including for off-grid installations) inside a building or structure before being terminated at an accessible disconnect—as long as they are in metal raceways, metal enclosures, or metal-clad cable that complies with 250.118(10). However, there are now additional installation requirements:

**Beneath roofs.** Wiring shall not be installed within 25 cm (10 in.) of the roof decking or sheathing except where directly below the roof surface covered by PV modules and associated equipment. Circuits shall be run perpendicular to the roof penetration point to supports a minimum of 25 cm (10 in.) below the roof decking. The 10-inch requirement is to prevent accidental damage from saws used by firefighters for roof ventilation during a structure fire.

**Flexible wiring methods.** Where flexible metal conduit (FMC) smaller than metric designator 21 (trade size  $3/4$ -in.) or Type MC cable smaller than 25 mm (1 in.) in diameter containing PV power circuit conductors is installed across ceilings or floor joists, the raceway or cable shall be protected by substantial guard strips that are at least as high as the raceway or cable. Where run exposed, other than within 1.8 m (6 ft.) of their connection to equipment, these wiring methods shall closely follow the building surface or be protected from physical damage by an approved means.

**Marking or labeling required.** The following wiring methods and enclosures that contain PV power source conductors shall be marked with the wording "Photovoltaic Power Source" using permanently affixed labels or other approved permanent marking: Exposed raceways, cable trays, and other wiring methods; covers; or enclosures of pull boxes and junction boxes; and conduit bodies in which any of the available conduit openings are unused.

**Marking and labeling methods and locations.** The labels or markings shall be visible after installation. Photovoltaic power circuit labels shall appear on every section of the wiring system that is separated by enclosures, walls, partitions, ceilings, or floors. Spacing between labels or markings, or between a label and a marking, shall not be more than 3 m (10 ft). Labels required by this section shall be suitable for the environment where they are installed.

When a positively grounded PV system is employed, it may be in the installer's best interest to use both proper color coding (such as having a white positive conductor and black or red negative conductors) and additional labeling to identify the system as positively grounded.

This is a violation because equipment-grounding conductors must be installed such that removal of any one module will not disrupt the array's reference to ground. Properly rated lugs and wire also need to be employed in a *Code-compliant* manner.



## Grounding

Grounding PV systems is a complex problem for installers and inspectors alike. The difference in grounding requirements imposed from one jurisdiction to the next can make it difficult for installers to keep their methods consistent. In addition, the requirements for equipment grounding and system grounding are separate and need to be evaluated separately.

**Equipment grounding.** PV modules and associated racks aside, equipment grounding is generally the least divisive of all of the grounding subjects. The *NEC* is very clear: "Exposed non-current-carrying metal parts of module frames, equipment, and conductor enclosures shall be grounded... regardless of voltage." For equipment and conductor enclosures, this is straightforward: A grounding conductor is used to bond all pieces of equipment to keep them all at the same electrical potential.

Unfortunately, using an equipment-grounding conductor (EGC) to bond PV modules and racks has never been simple or straightforward. While module manufacturers provide a location on their frames for the

bonding hardware, that location is generally midway along the bottom of the frame's long edge. This is not the most convenient place, especially if the modules are mounted parallel to a roof with minimal clearance. Additionally, the approved method of attaching the bonding hardware is not always well documented, and the appropriate hardware is not always included.

For bonding the racks to the EGC, installers have had to develop techniques without much guidance from manufacturers, and some poor choices were made in the past. One method used short lengths of THHN wire with ring terminals attached to each end. The ring terminals were then attached to the module frames via a self-tapping screw, which did not provide the proper electrical contact with the PV frame. The grounding method subsequently accepted industry-wide is to attach a tinned copper lay-in lug to each module and rack member, with an appropriately sized conductor bonding each of the modules and racks together. When installed correctly, this method is undoubtedly superior to many of the methods outlined in some manufacturer installation instructions.



**Left:** Aluminum lugs are not rated for outdoor use and also do not include stainless-steel set screws.

**Right:** When dissimilar metals are installed in direct contact with one another, the result is galvanic corrosion. Over time, this causes a loss of the bond to ground.

Recently, some PV manufacturers have specifically mentioned this method of grounding in their installation instructions, which is good news for the PV installation community. The tinned copper lay-in lugs used for this purpose eliminate the deteriorating effect of dissimilar metals (copper and aluminum) in contact with each other. These lugs come standard with a stainless-steel set screw and are rated for direct burial. There is a similar-looking lug on the market that is made from aluminum and is not outdoor-rated; this product does not include a stainless-steel set screw and is not appropriate for bonding PV modules.

Wiley Electronics' Washer, Electrical Equipment Bond (WEEB) bonds modules to racks; the racks are then bonded together to create an EGC that is eventually bonded to the other pieces of equipment, generally via a rooftop combiner box. Additional language to Section 690.43 seems to support using WEEB grounding clips and the use of the racks as the EGC, and the PV community has accepted WEEB products, but not universally. This ambiguity is not surprising since the subject matter is grounding, but it is also based on concerns such as the appropriateness of the UL listing used to test WEEB products and the lack of testing by individual module manufacturers. Ultimately, the question is whether the WEEB grounding solution is acceptable to your AHJ.

**System grounding.** With the 2008 *Code* requirements, system grounding is one of the most discussed and debated topics within the installer community. When the first grid-tied inverters were introduced to the U.S. market, it was difficult to make a connection from the inverter to the system ground. Today, all grid-tied inverters have ground lugs large enough to run a grounding electrode conductor (GEC) to the existing grounding system.

Section 690.47 deals specifically with system grounding. This section was completely rewritten in the 2008 *Code*, and again in 2011 resulting in a number of differing opinions and

methodologies. For example, a requirement in 690.47(C) is to size the DC GEC according to Section 250.166. This results in specifying an 8 AWG conductor or larger.

It is common to have grounding conductors serve as both the EGC and the GEC, allowable as long as the conductor is sized appropriately. For example, if a 7,000 W inverter is connected to a 40 A breaker within a main service panel, a minimum 10 AWG copper EGC is required per Section 250.122. However, according to Section 250.166, the GEC must not be smaller than 8 AWG. Therefore, for a single conductor to serve both purposes, it needs to be a continuous conductor no smaller than 8 AWG. Any EGCs connected to this conductor may not break the continuous GEC. In situations where this is not possible, it is necessary to run two separate conductors, one for the EGC and one for the GEC.

### Structural Codes

Electrical code violations receive the most attention when it comes to PV systems, but structural issues require examining the method of physically attaching PV arrays to roofs, poles, or the ground.

Most building departments use the *IBC* reference book, which, like the *NEC*, is published every three years with the 2009 *IBC* being most recent. The *IBC* requires compliance with attachment methods (modules to racks and racks to roof), as well as with equipment installation instructions. Properly flashing all roof penetrations, including structural attachments, is also required.

Although the *IBC* covers most of the structural issues that relate to PV installation, many local jurisdictions have specialty codes that go beyond these requirements. In areas with heavy snow loading, for example, a building department may require that installers evaluate the potential effects of snow drift and the additional dead load imposed by the PV array. In areas of high wind, the dynamic effect of wind needs to be evaluated and properly mitigated.

**Attachment and placement.** Correctly locating support rails as specified by the module manufacturer is also important. Many module warranties may be void if the manufacturer's specified support and attachment methods are not followed.

Module-handling methods are another issue. It is not uncommon to see work crews grabbing a module by one side and carrying it to the final location. While this is not a *Code* violation, former PV module engineer Diana Buttz points out that "carrying the module in this fashion puts an enormous amount of pressure and torque on that edge and can lead to seal failure." The correct way to carry modules, she explains, is to support both sides of the frame to minimize that stress.

Module placement and layout are critical, and often overlooked. For roof-mounted arrays, although not specified by the *IBC*, designing for adequate clearance is important. In its trainings, Sharp Solar recommends a minimum clear space of 12 inches around the array perimeter. When the modules are close to the roof eaves, 16 inches of clearance is recommended,



**Unlike the example shown at left, roof penetrations need to be properly flashed. Always follow the equipment manufacturer's instructions during installation.**

which allows room for future service, and reduces wind uplift around the roof edges. To determine the exact requirements for your location, work with the racking manufacturer and local building and fire departments. They can verify clearances as well as dynamic load allowances like wind, snow, seismic activity, and so forth.

If installing a system that deviates from the roof plane, consult a structural engineer or the rack manufacturer's engineers to evaluate the attachment method. However, the costs of engineering plus the additional racking materials may negate the value of the moderate increase in energy harvest.

### Familiarity Required

As PV systems become common, AHJs will be further scrutinizing installations for compliance with national electrical and structural codes, as well as local codes.

Getting familiar with the codes can help your PV project get off to a good start. But you don't necessarily have to wade through 840 pages of *NEC* technicalities to get there. Two great resources help sum up the most pertinent PV system code issues: First is the Solar America Board for Codes and Standards' (Solar ABCs) "Expedited Permit Process for PV Systems," which is available on the organization's website. A concise 61 pages, the document walks through the most relevant issues, explaining the Articles that apply as well as the reasoning behind the standard. The document includes a fill-in-the-blanks schematic that you can tailor to your system

and hand to your AHJ. Second, *NEC* expert John Wiles' *Photovoltaic Power Systems and the National Electrical Code: Suggested Practices* can help you navigate the complicated world of the *Code* (see Access).

### Access

Ryan Mayfield (ryan@renewableassociates.com) is a NABCEP-certified PV installer and ISPQ Affiliated Master Trainer. When he isn't trying to absorb all things solar, he is busy trying to influence the next generation by helping his kids solarize their backyard forts.

#### Manufacturers:

Burndy • [www.burndy.com](http://www.burndy.com)

ILSCO • [www.ilSCO.com](http://www.ilSCO.com)

Tyco Electronics • [www.tycoelectronics.com](http://www.tycoelectronics.com)

Wiley Electronics • [www.we-llc.com](http://www.we-llc.com)

#### Resources:

National Fire Protection Association (*NEC*) • [www.nfpa.org](http://www.nfpa.org)

Solar America Board for Codes and Standards • [www.solarabcs.org](http://www.solarabcs.org)

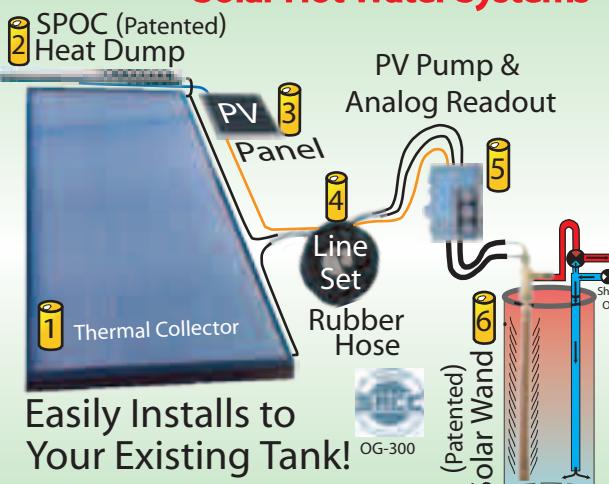
Southwest Technology Development Institute • [www.nmsu.edu/~tdi](http://www.nmsu.edu/~tdi)

Standard for Good Workmanship in Electrical Contracting (*NECA* 1-2006), National Electrical Contractors Association, 2006, paperback, 20 pages, \$40 • [www.necanet.org](http://www.necanet.org)



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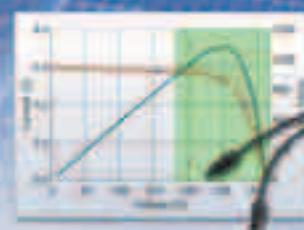
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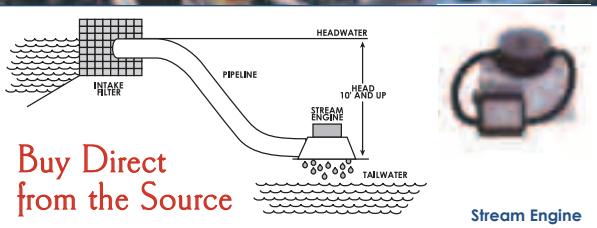
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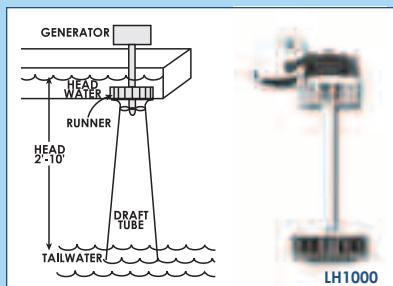
- Works with heads of 2 to 10 feet and large flows
- Low flow runner option

### Higher head turbine:

- Operates at heads of 10 feet and up
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# Conductor Sizing & Overcurrent Device Ratings

by John Wiles

Conductor sizes and overcurrent device ratings are critical to the safe, long-term operation of any electrical system, but are particularly important in PV systems where the outdoor environment can be extreme and the PV modules will be putting out energy for 40 years or more.

PV installers, plan reviewers and inspectors need to know how to do conductor sizing and overcurrent device ratings properly to get safe, reliable, and cost-effective PV systems. In general, the complete procedure we will cover can be used for any type of electrical circuit, except possibly HVAC and other motor protection circuits. A part of this procedure is in Section 690.8(B) of the 2011 *National Electrical Code*.

Historically, most residential and light-commercial electrical wiring has involved indoor wiring at room temperatures—30°C (86°F) or less. The ampacity tables in Section 310.15 and Table 310.16 of the *NEC* were developed with those conditions in mind. Additionally, the commonly used molded-case circuit breaker has a terminal temperature limit of 75°C (167°F) and is rated for use with conductors with 75°C insulation. These circuit breakers have a rated maximum operating temperature of 40°C (104°F), which is greater than typical indoor room temperatures. If the circuit breaker is connected with conductors rated at 75°C and operates in a temperature less than 30°C, then electricians typically don't perform temperature corrections for ampacity on the conductors nor do they have to consider terminal temperature limits. They just look up an ampacity value for the conductor being used out of the 75°C column in *NEC* Table 310.16 and that's it as far as temperatures are concerned.

However, direct current (DC) PV conductors normally operate in an environment that requires conductors with 90°C insulation, and appropriate temperature and conduit fill corrections must be applied, along with addressing the operating temperature limitations of overcurrent devices.

Throughout the code, circuits are sized based on 125% of the continuous load plus the noncontinuous load—see *NEC* Sections 210.19(A)(1) and 215.2(A)(1). This requirement establishes a situation where conductors and overcurrent devices are not subjected to continuous current more than 80% of rating (note:  $1 \div 1.25 = 0.80$ ). The term "continuous current" is used because PV modules produce current and are not loads. The PV ampacity calculations assume that all PV currents are continuous (more than three hours in duration) and are adjusted for worst-case conditions. This

NEC requirement has evolved over 60 years to prevent nuisance tripping of overcurrent devices.

## Sizing Conductors

In the *Code*, there are several requirements that must be met in sizing conductors.

First is the definition of ampacity found in Article 100. Ampacity is "the current in amperes that a conductor can carry continuously under the conditions of use without exceeding its temperature rating."

Next is the 125% requirement in 210.19(A)(1) and 215.2(A)(1): "The minimum feeder-circuit conductor size, *before the application of any adjustment or correction factor*, shall have an allowable ampacity not less than the noncontinuous load plus 125 percent of the continuous load." The emphasized words indicate that there's no requirement to apply the 125% *and* the conditions of use at the same time.

Section 110.14(C) requires that the temperature of the conductor in actual operation not exceed the temperature rating of terminals on the connected equipment, primarily to prevent nuisance tripping of overcurrent devices.

An added requirement for listed equipment such as overcurrent devices is that they not be used in a manner that deviates from the listing or labeling on the product (110.3(B)). Most PV source-circuit combiners operating outdoors in the sunlight will have internal temperatures that exceed the 40°C rated operating temperatures of commonly used fuses and circuit breakers.

The following method of determining ampacity and conductor size meets three of the requirements above. (Terminal temperature limitations are not addressed in this article.) It also determines the rating of the overcurrent device where such a device is required.

## Step 1

Determine the continuous current in the circuit. For code calculations, all DC and AC PV currents are considered continuous and are based on worst-case scenario output or are based on safety factors applied to rated output.

**A. PV DC Circuits.** In the DC PV source and DC PV output circuits, the continuous currents are defined as 1.25 times the rated short-circuit current  $I_{SC}$ . This 125% factor accounts for normal and expected values of sunlight intensity (irradiance)

that exceed the standard rating value of 1,000 W per m<sup>2</sup>. If a module or module string had an  $I_{SC}$  of 7.5 A, the continuous current would be  $1.25 \times 7.5 = 9.4$  A. 690.8(A)(1).

If three strings of modules (module  $I_{SC}$  = 8.1 A) were connected in parallel through a fused combiner, the PV output circuit of the combiner would have an  $I_{SC}$  of  $3 \times 8.1 = 24.3$  A. The continuous current in this circuit would be  $1.25 \times 24.3 = 30.4$  A. 690.8(A)(2)

**B. AC Inverter Output Circuits.** In the AC output circuits of a grid-tied or stand-alone inverter, the continuous current is taken at the full power rated output of the inverter. It is not measured at the actual operating current of the inverter (which may be a small fraction of the rated current if a small PV array is connected to a large inverter). The rated output current is usually specified in the manual, but may be calculated by dividing the rated power by the nominal AC voltage. For stand-alone inverters, which can provide some degree of surge current, it is the rated power that can be delivered continuously for three hours or more (690.8(A)(3)). Three hours is the time period defined in Article 100 for "continuous load."

In some cases, the inverter specifications will give a rated current that is higher than the rated power divided by the nominal voltage. In that situation, the higher current should be used.

For a grid-tied inverter operating at a nominal voltage of 240 V and a rated power of 2,500 W, the continuous current would be:

$$2,500 \text{ W} \div 240 \text{ V} = 10.4 \text{ A}$$

An example stand-alone inverter operates at 120 V and can surge to 3,500 W for 60 minutes. However, it can only deliver 3,000 W continuously for three hours or more. The rated AC output current would be:

$$3,000 \text{ W} \div 120 \text{ V} = 25 \text{ A}$$

**C. Battery Currents.** The design current between a battery and an inverter in either a stand-alone system or a battery-back up grid-tied system must be based on the rated continuous output power of the inverter at the lowest input battery voltage that can provide that output power (690.8(A)(4)). Normally the output current from the battery in the inverting mode is greater than the current to the battery in the charging mode. This current in the inverting mode is usually marked on the inverter or found in the specifications.

The current in inverting mode can be calculated by taking the inverter rated AC output power, dividing it by the lowest battery voltage that can sustain that power, and also by dividing by the inverter DC-to-AC conversion efficiency at that battery voltage and power level. For example:

A 4,000 W inverter can operate at that power with a 44 V battery input and under these conditions has a DC-to-AC conversion efficiency of 85%. The DC continuous current will be:

$$4,000 \text{ W} \div 44 \text{ V} \div 0.85 = 107 \text{ A}$$

On single-phase inverters, the DC input current is rarely smooth and may have 120 Hz ripple current with a larger RMS (root mean square) value than the calculated continuous current. The inverter technical specifications should list the greatest continuous current and that number should be used when given.

## Step 2

Calculate the rating of the overcurrent device, where required. Since PV modules are current-limited, overcurrent devices are frequently not needed for one or two paralleled strings of PV modules. In systems with three or more paralleled strings of modules, overcurrent devices are usually required in each string to protect not only the conductors, but also the module internal connections.

**A. Rating Determined from Continuous Currents.** The overcurrent device rating is determined by taking the continuous current for any of the circuits listed in Step 1 and increasing it by 125%. This helps ensure that the overcurrent device is operating under 80% of its ampacity rating (even under the high irradiance conditions [ $1.25 \times I_{SC}$ ] that we calculated in Step 1A), and thus meets *NEC* requirements. Calculated non-standard overcurrent device values should be rounded up to the next standard rating in most cases to ensure that under continuous currents, the overcurrent device will operate at no more than 80% of rating.

In a very few rare cases, an overcurrent device installed in an enclosure or an assembly may be listed as an assembly for operation at 100% of rating. In these cases, the overcurrent device rating is the same as the continuous current (listed in Step 1) and no 125% factor is used. (I know of no such PV system devices at this time.)

A circuit has a continuous current of 15 amps. The overcurrent device would have a rating of 18.75 A ( $1.25 \times 15$ ). However, there are no standard overcurrent devices rated at 18.75 A, so a 20 A overcurrent device needs to be used.

**B. Operating Temperature Affects Rating.** Overcurrent devices are listed for a maximum operating temperature of 40°C (104°F). PV combiner boxes operating in outdoor environments may experience ambient temperatures as high as 50°C. When the combiner enclosures are exposed to sunlight, the internal temperatures may reach or exceed 55 to 60°C. Any time the operating temperature of the overcurrent device exceeds 40°C, it may be subject to nuisance trips at current values lower than its rating. In this situation, the manufacturer must be consulted to determine an appropriate derating. At high operating temperatures, an overcurrent device with a higher rating will activate at the desired current. In PV source circuits, the marked rating of the revised overcurrent device (under cold-weather conditions) must not exceed the ampacity of the conductors or the maximum series fuse value marked on the back of the module.



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# Home on the Range

by Kathleen Jarschke-Schultze



Sixteen years ago, I received a gas range as a surprise gift from my husband Bob-O (see "Home & Heart" in *HP40*). After more than a decade and a half of hard use, I felt it was time for a range upgrade. In many cases, living beyond the reach of the power lines (off-grid) determines appliance selection. The limited choice of kitchen ranges illustrates the difficulty of being off-grid in the predominately grid-tied United States.

### Classical Gas

My brother and his wife's house flooded several years ago. As part of the extensive reconstruction, they had to replace all of their appliances. My sister-in-law took the opportunity to switch out her electric range with a gas-fueled one. Her new range had two ovens—a smaller oven on top, for pizzas, cookies, and the like, plus a standard-sized oven below.

Melva told me she did not expect to use the smaller oven much, but it turned out to be her favorite. Why heat the larger oven when the small one would do? I was impressed. I started to look at options for upgrading my own range.

### Say What?

Bob-O purchased my old five-burner Peerless-Premier gas range in 1994. At the time, it was from one of only two stove manufacturers in the United States who made a gas stove that

*did not require any electricity to operate.* Still, those companies, Peerless-Premier Appliance Co. and Brown Stove Works, remain the only two.

Both companies make gas models that use electricity for electronic ignition to light the burners and oven. Some of their ranges also use electricity to run a clock/timer and light in the oven. But none of the models *require* electricity. All the burners and the oven can be match-lit.

Every other gas range manufacturer places an electric glow bar in the oven to initially light the burner, which then stays on as the burner cycles to maintain the temperature. These gas ranges must have electricity to operate. You cannot light the oven with a match. It's deemed a safety feature, eliminating pilot lights. I suspect it is just cheaper.

With this type of ignition, the thermostat or electronic control switches power to the glow bar, or oven igniter and gas valve circuit. As power flows through the igniter, it heats and draws current (measured in amps). Once the oven igniter draws a specific amount of current, the oven gas valve opens, allowing flow to the burner where the glowing-hot igniter (glow bar) ignites the gas. Power must continually flow through the igniter and oven gas valve for gas to be released into the oven burner to create a flame. Once the set temperature is achieved, the control stops all power to the

ignition circuit, which causes the igniter to dim and the oven gas valve to close, stopping any burner flame. Cycling on and off continues to maintain the specific temperature the control is set for. The average oven igniter draws 2.5 to 3.0 A, or 300 to 360 W.

Our old stove did not have this glow bar, which would have been a serious draw on our off-grid electric system. A new one couldn't have it, either.

### I've Been Searchin'

After 16 years, my old stove had become irritating. It worked, but the oven door began sticking (and could not be fixed), the timer's limit was two hours, and when switched to clock mode, the stove emitted a grating, pulsing buzz. I wanted a range with options, fun, and practical features. I wanted two ovens, or different Btu burners or sealed burners. I wanted more.

What I found were salespeople who had no idea how much electricity a new gas range uses. They were totally clueless. Their attitude was, "Why would you care?" I ended up lecturing a few on unnecessary energy consumption and equally unnecessary safety features.

I found a Maytag model I liked a lot. I talked myself into thinking that if the igniter didn't cycle on much, maybe I could get away with it, at least in the winter when our microhydro system kicked in and we had plenty of energy. In the summer, I could use my solar cookers.

I wrote to Maytag, explaining that I lived off-grid on renewable energy, so power conservation was critical. I asked them if I cooked, say, a casserole in the oven for one hour at 350°F, how much electricity the oven igniter would use during that time.

Several weeks later, I received my reply. "Madam," they wrote, "It is a gas range and does not use electricity."

Not wanting to waste my time educating a clearly oblivious person, I moved on. After finding out that buying and installing a commercial gas range in our home would negate our house fire insurance policy, I went back to Peerless-Premier and was pleasantly surprised with their product offerings.

### Old Dog, New Tricks

In the 16 years since my first range, Peerless-Premier developed some innovations. These include sealed burners and, on their Pro Series, burners with various heat ranges and a continuous grate surface, so pots and pans can be scooted around easily.

I chose the Premier Pro Series P36S318BP, which features six sealed top burners: one at 15,000 Btu; one at 12,000 Btu; three at 9,100 Btu; and one simmer burner with 600 to 6,000 Btu. The oven burner checks in at 17,000 Btu. Every gas range they ship has the parts and instructions to switch from natural gas to propane. This model I chose has no clock or timer but sports a 1 1/2-inch black porcelain vent-rail cap at the back. The range is intended for an island application, but the one side that shows in my kitchen is black enamel and looks fine.

The front is stainless steel with large handles and control knobs.

The six-burner grates form a continuous surface across the top. The middle two grates can be replaced with a large, heavy nonstick griddle (included). On my old stove, the griddle in the middle had just one burner, which was more frustrating than effective—resulting in uncooked pancakes on one end and burned ones in the middle.

Now I find myself using the different burners daily—starting the soup on the hottest burner, then moving it to the simmer burner. The griddle stays at an even temperature along its entire length. The hottest burner was very handy this past canning season—I was able to get the big pot of water to a nice rolling boil in no time.

### Bug or Feature?

All that being said, I have run into a dreaded "safety feature"—the control knobs. On every other gas range I have used, the flame starts out small and gets larger and hotter as you turn the knob clockwise. On this range, turning the knob slightly counterclockwise initiates the piezo electric igniter until the flame is lit. Continuing to turn counterclockwise, the burner is now at its highest flame, diminishing as you continue turning. When you get to the end of the knob's range, the flame is at its lowest. You cannot make that flame go any lower.

At first I thought, "Well, that's okay, I'll get used to it." Then I realized that the simmer burner (rated at 600 to 6,000 Btu) could only be lowered to a boil. I have remedied this by stacking cast-iron grates from previous scrapped gas ranges on the burner grate and raising the pot well above the flame. The extra grates are quite large and heavy, and therefore sturdy enough to be safe. I use them on top of the woodstove in winter to place pots of soup or beans.

One other feature disappointed me. The high-Btu burner is positioned on the back left corner of the range top. The simmer burner is directly in front of it. I called the company to see if I could exchange the position of the two. The tech there told me he gets this request at least once a day. He said the engineers designed it so you could not rearrange the burners.

Obviously, the engineers were not cooks. "Simmering on the back burner" is a common saying. And why would you ever want to be reaching over another burner to stir-fry in your wok or lift canning jars from boiling water?

Impractical bugs aside, I do like my new range. It is functional, beautiful and doesn't tax our RE systems. We tried to measure its energy use when off, but it would not even register on our Kill-A-Watt meter. I anticipate using this workhorse for years to come.

### Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) can stand the heat and can't stay out of the kitchen at her off-grid home in northernmost California.



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# Climate & SHW System Design

Historical climate data used to design home heating systems is less valuable for designing a solar hot water (SHW) system. This is true even when the SHW system has a home heating component. SHW systems are usually designed to displace only a portion of the heating load and leave the worst-case situations to a backup system. Plus, heating degree-days and minimum temperatures include *nighttime* temperatures, which skew the data for estimating SHW system performance, since system production depends on the *daytime* outside ambient temperature, and this isn't usually recorded separately from night lows.

The major factor in SHW production is irradiance (solar intensity), which causes a collector's heat gain. Understanding irradiance is intuitive: High irradiance gives us sunburns, whereas cloudy skies might not. Irradiance is also affected by altitude, and annual solar energy is affected by a location's distance from the equator, but this is less of a limiting factor than clouds. Good irradiance equals good collector heat gain.

The most useful historical data to estimate SHW output would be average daily daytime temperatures—but accurate data is scarce. So we estimate SHW system production in terms of its efficiency and heat loss. The Solar Rating and Certification Corporation (SRCC; [www.solar-rating.org](http://www.solar-rating.org)) gives us some guidance with a table of performance published for each certified collector. Three levels of irradiance (heat gain) and five categories of temperature difference (heat loss) are classified. Collector outputs in thousands of Btu per collector per day are given in the 15 cells in the performance matrix. Temperature difference (delta T or  $\Delta T$ ) is given as a formula of inlet temperature ( $T_i$ ) minus ambient temperature ( $T_a$ ). The greater the difference between operating temperature and ambient temperature, the greater the heat loss and the lower the energy production.

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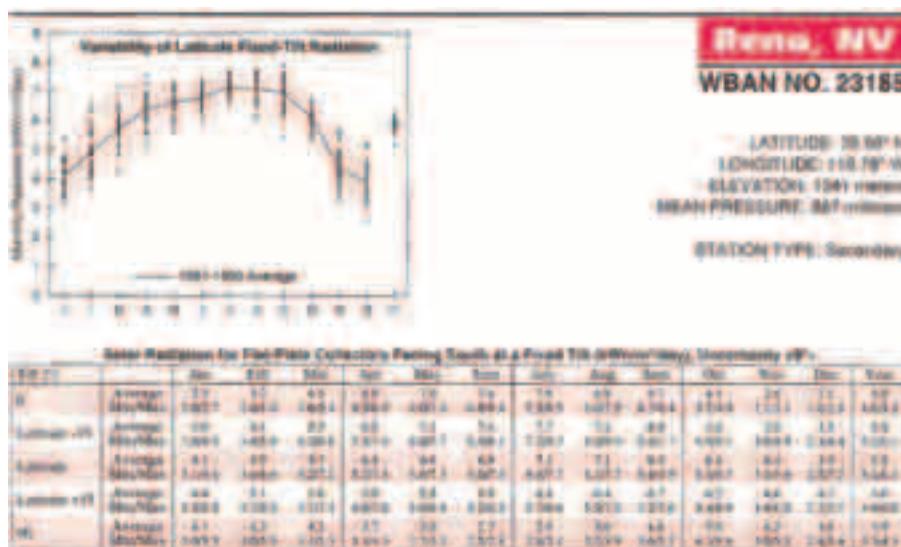
For more information on using the SRCC matrix, visit [www.homepower.com/webextras](http://www.homepower.com/webextras).



The five categories in the matrix are listed as A to E in ascending order of temperature difference—for solar water heating, the "C" category is most accurate for most locations in the United States. The other categories apply to swimming pool heating, water heating in very harsh climates, space heating, and very high temperature requirements. The three levels of insolation (irradiance measured perpendicular to the sun's rays) are given as 2,000, 1,500, and 1,000 Btu per square foot of energy available as an annual average. Most U.S. regions fall in or around the 1,500 Btu level. The desert Southwest is closer to the 2,000 Btu level and the Pacific Northwest falls between the 1,000 and 1,500 Btu levels. (Alaska is the only state with locations that have annual average insolation levels at or below 1,000 Btu/ft.<sup>2</sup>/day.)

The National Renewable Energy Laboratory's National Solar Radiation Data Base (<http://rredc.nrel.gov/solar/pubs/redbook/>) provides the annual average insolation of hundreds of metro areas in the United States. The averages are given as kWh per square meter per day. Use the multiplier 317.1 to convert the annual averages from kWh/m<sup>2</sup>/day to Btu/ft.<sup>2</sup>/day. The 317.1 is a shortcut calculation that includes the conversions of 3,412 Btu = 1 kWh and 10.76 ft.<sup>2</sup> = 1 m<sup>2</sup>.

—Chuck Marken



Solar radiation data can be used to determine the Btu level for your area. For example, looking at data for Reno, Nevada, a collector set at latitude would receive an annual average of 5.4 kWh/m<sup>2</sup>/day, which translates into 1,712 Btu/ft.<sup>2</sup>/day.

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